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ATLAS AND EPITOME

OF

HUMAN HISTOLOGY

AND

MICROSCOPIC ANATOMY

BY

DOCTOR JOHANNES SOBOTTA

Of the University of Würzburg, Bavaria

ROYAL COLLEGE OF PHYSICIANS
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EDITED, WITH EXTENSIVE ADDITIONS, BY

G. CARL HUBER, M.D.

Junior Professor of Anatomy and Director of the Histologic Laboratory at the University of Michigan

Authorized Translation from the German

With 171 Illustrations on 80 Lithographic Plates, and 68 Text Illustrations

PHILADELPHIA AND LONDON
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This American Edition is gratefully and respectfully dedicated by the Editor to

DOCTOR HERMANN KIEFER

a long time Regent of the University of Michigan, in recognition of his services to Medical Education.

EDITOR'S PREFACE.

Considering the fact that there are already a number of excellent and widely known text-books and atlases of histology, it may seem like a hazardous venture to enter upon the field with something new. Sobotta has, however, in his "Atlas und Grundriss der Histologie und mikroskopischen Anatomie des Menschen," succeeded in combining an abundance of well-chosen and most accurate illustrations with a concise text in such a manner as to make it both atlas and text-book.

The illustrations comprise eighty lithographic plates, which have been reproduced with the aid of over thirty colors, and sixty-eight figures reproduced with the aid of photomechanical methods. The publishers have spared no expense in the reproduction of plates and figures; they have been printed with the greatest care and exactness, and portray most faithfully the microscopic preparations reproduced. The original drawings which formed the basis of nearly all the illustrations of this volume were made after the following method, suggested by Sobotta: The preparations were photographed under the same magnification as that under which they were drawn. The photographs were then used as a basis for the drawings, in that outline drawings, even to the finest details, were traced on tracing-paper; these outline drawings were then transferred to drawing-paper. This method assures exactness of magnification; by means of it distortion is avoided, and during the preparation of the drawing the photograph serves as a control picture. As the details of a drawing, especially of a general view under low magnification, are nearly always filled in under a lens of higher power, there is always a danger that the cell-nuclei are represented larger than the magnification permits; this is avoided by the above method. In a few instances a number of photographs were combined to make a single drawing. Some two hundred microphotographs were made for the figures represented in the atlas. Nearly all the illustrations in the volume were made under relatively low magnifications, such as are used by the majority of students in the general microscopic courses. Attention may especially be drawn to numerous figures portraying, under very low magnification, a general view of entire organs or parts of organs, thus giving the student more accurate mental pictures of the relations of the component structures than can be gained by a study of figures giving small areas under higher magnification.

The great majority of the illustrations were made from sections prepared from human tissues, obtained from individuals who had been executed; some few from tissues taken from a body two and a half hours after death. The tissues employed may therefore be regarded as fresh and normal in every respect. Nearly all the microscopic preparations reproduced were made by Sobotta; a few were obtained from the anatomic collection at Würzburg; some few from private collections; for these, appropriate credit is given in the legends describing the respective figures. Tissues from animals served the purpose when it was desirable to illustrate a special structure or a characteristic arrangement of tissue-elements, or in a few instances when human tissues were not available.

The text is as brief and concise as possible. Neither references to literature nor disputed views could therefore find place therein. It is limited to the generally recognized facts of microscopic anatomy, and is written connectedly and without special reference to the figures. In assuming editorial responsibility for the text, the editor of this edition felt justified in bringing the views expressed therein in conformity with his own observations. He has thus annotated and altered very freely certain portions of the sections on the adenoid tissues, blood and the blood-forming organs, muscular tissues, special sense organs, and peripheral nerve distributions, and has made other minor changes as occasion permitted. Additions to the text were now and then made. Certain sections were rearranged without material alterations in contents, and in many instances he has incorporated the foot-notes in the text.

The illustrations, especially those on the lithographic plates, receive especial explanation, the legends appearing on the left side, while the plates are on the right. Plates and text are therefore to a certain extent independent. The reader may follow the text independently of the plates, or interpret the latter by the help of the legends.

The translation from the German was executed by Dr. Lydia M. DeWitt; the editor is also under grateful obligation to her for assistance in proof-reading.

G. CARL HUBER.

UNIVERSITY OF MICHIGAN,
ANN ARBOR, MICHIGAN.

CONTENTS.

THE HISTOLOGY OF CELLS AND TISSUES. PAGE

I. The Cell 17
II. The Tissues of the Human Body 28
Epithelial Tissues 29
Supporting or Connective Tissues 40
Muscle Tissue 62
Nervous Tissues 70

THE MICROSCOPIC ANATOMY OF THE ORGANS.

I. The Skeletal System 81
Bone and Osseous Tissue 81
Bone Development 85
II. The Organs of the Muscular System 91
Muscles 91
Tendons 93
III. The Organs of the Nervous System 95
1. The Central Nervous System 95
2. The Peripheral Nervous System 107
(a) The Peripheral Nerves 107
(b) The Peripheral Ganglia 108
(c) The Nerve-endings 109
IV. Blood and Lymph Vascular System 111
Heart 111
Blood-vessels 115
Lymphoid Tissue 120
Spleen 124
Thymus 126
V. The Digestive Organs 128
Oral Cavity 129
The Teeth 130
The Tongue 136
The Adenoid Structures of the Tongue and Pharynx . . 138
The Esophagus 141
The Stomach 143
The Small Intestine 145
The Large Intestine 149
The Lymphatic Structures of the Intestines 149

PAGE
The Blood- and Lymph-vessels and Nerves of the Stomach and Intestines 151
The Salivary Glands 153
The Liver 161
VI. The Urinary Organs 166
The Kidneys 166
The Efferent Urinary Passages 173
VII. The Male Reproductive Organs 175
Testes 175
The Efferent Seminal Passages 180
VIII. The Female Reproductive Organs 185
Ovary 185
Oviduct, Uterus, and Vagina 191
IX. The Respiratory Organs 196
The Nasal Cavity 196
Larynx, Trachea, and Bronchi 197
The Bronchial Branches and Lungs 198
The Thyroid Gland 201
X. The Skin 201
Skin, Epidermis, and Cutis 201
The Epidermal Structures of the Skin 205
The Hair 205
The Nails 209
The Glands of the Skin 210
Mammary Glands 213
XI. The Special Sense Organs 214
The Organ of Vision 214
Tunica Externa Bulbi 215
Tunica Media Bulbi 217
Tunica Interna Bulbi 221
Optic Nerve 227
Vitreous Body and Zonula Ciliaris 228
Lens 229
Auxiliary Apparatus of the Eye 229
Eyelid 229
Lachrymal Gland 231
Organ of Hearing 232
External Ear 232
Inner Ear 233
Cochlea 234
Olfactory Organ 238
Organ of Taste 238

INDEX 241

COLORED PLATES.

- Plate 1.—Mitosis.
  - Figs. 1–10.—Ten Stages of Indirect Nuclear Division.
- Plate 2.—Epithelial Tissues.
  - Fig. 1.—Cell Boundaries.
  - Fig. 2.—Squamous Epithelium.
  - Fig. 3.—Cylindric Epithelium.
- Plate 3.—Epithelial Tissues.
  - Fig. 1.—Transitional Epithelium.
  - Fig. 2.—Stratified Ciliated Epithelium.
  - Fig. 3.—Ciliated Epithelium of the Epididymis.
  - Fig. 4.—Pigment Epithelium.
- Plate 4.—Connective Tissues.
  - Fig. 1.—Reticular Connective Tissue.
  - Fig. 2.—Interstitial Cells of Testis.
  - Fig. 3.—Mast-cells.
  - Fig. 4.—Connective-tissue Cells from Cornea.
- Plate 5.—Blood and Bone-marrow.
  - Figs. 1–21.—Human Blood-corpuscles.
  - Figs. 22–31.—Elements of Bone-marrow.
- Plate 6.—Muscular Tissues.
  - Fig. 1.—Pigmented Connective-tissue Cells.
  - Fig. 2.—Branched Striated Muscle-fibers.
  - Fig. 3.—Longitudinal Section of Heart Muscle.
  - Fig. 4.—Transverse Section of Heart Muscle.
- Plate 7.—Nerve-cells.
  - Fig. 1.—Isolated Multipolar Ganglion-cells.
  - Fig. 2.—The Same with Tigroid Substance Stained.
  - Fig. 3.—Spinal Ganglion-cells.
- Plate 8.—Bone Development. Embryonal Finger in Longitudinal Section.
- Plate 9.—Bone Development. Embryonal Forearm in Cross-section.
- Plate 10.—Bone Development. Embryonal Femur in Cross-section.
- Plate 11.—Bone Development.
  - Fig. 1.—Embryonal Metacarpal Bone in Longitudinal Section.
  - Figs. 2–6.—Bone Formation and Resorption in the Lower Jaw of an Embryo.
- Plate 12.—Muscle.
  - Fig. 1.—Transverse Section of the Omohyoideus.
  - Fig. 2.—A Neuromuscular Spindle from the Same Muscle.

- Plate 13.—Spinal Cord. Topographic Representation of the Cervical Cord. (Carmin Stain.)
- Plate 14.—Spinal Cord. Transverse Section of the Lumbar Cord. (Weigert Stain.)
- Plate 15.—Medulla Oblongata. Topographic Representation of the Prolongation of the Cord in the Olivary Region. (Weigert Stain.)
- Plate 16.—Cerebellum and Heart.
    - Fig. 1.—General View of the Structure of the Cerebellum. (Carmin Stain.)
    - Fig. 2.—Papillary Muscle of Heart.
- Plate 17.—Cerebellum, Sympathetic Ganglion.
    - Fig. 1.—Cerebellum in Weigert Stain.
    - Fig. 2.—Small Sympathetic Ganglion.
- Plate 18.—Cerebral Cortex; Tactile Corpuscle.
    - Fig. 1.—Cerebral Cortex in Weigert Stain.
    - Fig. 2.—Taste-buds, Stained by the *Intra-vitam* Methylene-blue Stain.
- Plate 19.—Peripheral Nerves.
    - Fig. 1.—Peripheral Nerve, General View.
    - Fig. 2.—Portion of Fig. 1 under Higher Magnification.
- Plate 20.—Peripheral Ganglia.
    - Fig. 1.—Sympathetic Ganglion in Weigert Stain.
    - Fig. 2.—Spinal Ganglion in Weigert Stain.
- Plate 21.—Arteries.
    - Fig. 1.—Transverse Section of Aorta.
    - Fig. 2.—Transverse Section of Radial Artery.
- Plate 22.—Blood-vessels.
    - Fig. 1.—Transverse Section of a Vein Having Muscular Walls.
    - Fig. 2.—A Transverse Section of a Medium-sized, Fig. 3, of a Small, and Fig. 4, of a Very Small Artery.
- Plate 23.—Lymph-gland, Spleen.
    - Fig. 1.—General View of a Cervical Lymph-gland.
    - Fig. 2.—Rabbit's Spleen, Injected.
- Plate 24.—Spleen.
    - Fig. 1.—General View of Human Spleen.
    - Fig. 2.—Spleen Nodule under Higher Magnification.
- Plate 25.—Thymus.
    - Fig. 1.—General View of a Child's Thymus.
    - Fig. 2.—Hassal's Corpuscle from Thymus of an Adult.
- Plate 26.—Lip. General View of Cross-section of Lip.
- Plate 27.—Tooth Development.
    - Fig. 1.—First Stage of Tooth Development.
    - Fig. 2.—Third Stage.
- Plate 28.—Tooth Development.
    - Fig. 1.—Second Stage.
    - Fig. 2.—Fourth Stage.
- Plate 29.—Tongue.
    - Fig. 1.—Mucous Membrane of Tongue.
    - Fig. 2.—Papillæ of Tongue.
- Plate 30.—Tonsils. General View of Palatal Tonsil.

- Plate 31.—Tongue.
  - Fig. 1.—Papilla Circumvallata.
  - Fig. 2.—Wandering of Lymphocytes through the Epithelium of the Tonsil.
- Plate 32.—Esophagus. General View of Esophagus.
- Plate 33.—Esophagus, Stomach.
  - Fig. 1.—Esophagus.
  - Fig. 2.—General View of the Structure of the Wall of the Stomach.
- Plate 34.—Stomach.
  - Fig. 1.—General View of Mucous Membrane of Stomach.
  - Fig. 2.—Stomach Glands under Higher Magnification.
- Plate 35.—Stomach, Duodenum.
  - Figs. 1 and 2.—Portions of Fundus Glands of Stomach.
  - Fig. 3.—General View of the Duodenum.
- Plate 36.—Small Intestine. General View of Jejunum.
- Plate 37.—Small Intestine.
  - Fig. 1.—Mucous Membrane and Villi.
  - Fig. 2.—Intestinal Glands.
- Plate 38.—Large Intestine.
  - Fig. 1.—General View of Structure of Wall of Large Intestine.
  - Fig. 2.—Mucous Membrane of Rectum.
- Plate 39.—Intestinal Epithelium, Goblet-cells.
  - Fig. 1.—Villi of Intestine.
  - Fig. 2.—Glands of Large Intestine.
- Plate 40.—Transverse Section of Vermiform Appendix, Giving General View.
- Plate 41.—Nerve-plexus of Intestine.
  - Fig. 1.—Plexus Myentericus.
  - Fig. 2.—Plexus Submucosus.
- Plate 42.—Salivary Glands.
  - Figs. 1 and 2.—Sublingual Gland.
- Plate 43.—Salivary Glands.
  - Fig. 1.—Submaxillary.
  - Fig. 2.—Parotid.
- Plate 44.—Pancreas.
  - Fig. 1.—General View.
  - Figs. 2 and 3.—Detail Figures of Pancreas.
- Plate 45.—Liver.
  - Fig. 1.—General View of Liver.
  - Fig. 2.—Columns of Liver-cells.
- Plate 46.—Liver.
  - Fig. 1.—Injected Liver of Rabbit.
  - Fig. 2.—Bile Capillaries of Rabbit's Liver.
- Plate 47.—Liver. Doubly Injected Rabbit's Liver. (Bile Capillaries Blue, Blood Capillaries Red.)
- Plate 48.—Kidney. General View of Structure of Kidney.
- Plate 49.—Kidney. Cortical Substance of Kidney.
  - Fig. 1.—General View.
  - Fig. 2.—Glomerular Capsule and Uriniferous Tubule.
  - Fig. 3.—Brush Border.

Plate 50.—Kidney.
  Fig. 1.—Medullary Substance.
  Fig. 2.—Kidney Injected through Arteries.
Plate 51.—Kidney.
  Fig. 1.—Injected Glomeruli.
  Fig. 2.—Kidney of Guinea-pig, Injected through Veins.
Plate 52.—Ureter, Bladder.
  Fig. 1.—Bladder.
  Fig. 2.—Ureter.
Plate 53.—Testis.
  Fig. 1.—General View of Testis, Epididymis, and Vas Deferens.
  Fig. 2.—General View of Lobule of Testis.
Plate 54.—Testis.
  Figs. 1-5.—Phases of Spermatogenesis.
Plate 55.—Epididymis.
  Fig. 1.—Head of Epididymis (Ductus Efferentes).
  Fig. 2.—Body of Epididymis (Ductus Epididymidis).
Plate 56.—Seminal Passages, Spermatic Cord.
  Fig. 1.—Ductus Deferens.
  Fig. 2.—Spermatic Cord.
Plate 57.—Urethra, Seminal Vesicle.
  Fig. 1.—Pars Membranacea Urethræ.
  Fig. 2.—Seminal Vesicle.
Plate 58.—Prostate.
  Fig. 1.—Prostate.
  Fig. 2.—Muscular Trabeculæ of Frog's Bladder.
Plate 59.—Ovary.
  Fig. 1.—Cortical Substance of Ovary.
  Fig. 2.—Ovum and a Part of Discus Proligerus.
Plate 60.—Ovary, Oviduct.
  Fig. 1.—Transverse Section of Oviduct.
  Fig. 2.—Ovary of New-born Child.
Plate 61.—Uterus.
  Fig. 1.—General View of Uterus.
  Fig. 2.—Uterine Mucous Membrane.
Plate 62.—Suprarenals.
  Fig. 1.—General View.
  Fig. 2.—Under Higher Magnification.
Plate 63.—Nasal Mucous Membrane.
  Fig. 1.—Olfactory Region.
  Fig. 2.—Respiratory Region.
Plate 64.—Trachea. General View of Structure of Trachea.
Plate 65.—Lungs. Vascular Injection of Lung.
Plate 66.—Lung, Thyroid Gland.
  Fig. 1.—Bronchus.
  Fig. 2.—Thyroid Gland.
Plate 67.—Skin.
  Fig. 1.—General View of Structure of Skin.
  Fig. 2.—Injection Preparation of Skin.

Plate 68.—Skin, Hair.
  Fig. 1.—Papillæ of Epidermis and Corium.
  Fig. 2.—Cells of Stratum Dentatum.
  Fig. 3.—Longitudinal Section of Lower Portion of Root of Hair.
Plate 69.—Hair. General View of Structure of Scalp, with Longitudinal Section of Hairs.
Plate 70.—Hair.
  Figs. 1 and 2.—Transverse Sections of Root of a Hair in the Middle and Lower Portion.
Plate 71.—Hair, Sweat-glands.
  Fig. 1.—Cross-section of Hair (General View).
  Figs. 2–4.—Axillary Sweat-glands.
  Fig. 5.—Sweat-glands of Scalp.
Plate 72.—Sebaceous Glands and Nails.
  Fig. 1.—Sebaceous Gland.
  Fig. 2.—Cross-section of Nail.
  Fig. 3.—Longitudinal Section of Nail.
Plate 73.—Mammary Gland.
  Fig. 1.—General View.
  Fig. 2.—Detailed View of Human Mammary Gland.
  Fig. 3.—Detailed View of the Mammary Gland of the Mouse.
Plate 74.—Eye. General View of the Eyeball (Horizontal Section).
Plate 75.—Eye.
  Fig. 1.—Cornea.
  Fig. 2.—Cross-section of the Three Tunics of the Eye.
Plate 76.—Eye.
  Fig. 1.—Cornea, Iris, Corpus Ciliare.
  Fig. 2.—Lens.
Plate 77.—Eye.
  Fig. 1.—Cross-section of Retina.
  Fig. 2.—Fovea Centralis.
  Fig. 3.—Ora Serrata.
Plate 78.—Eye, Lachrymal Gland.
  Fig. 1.—Entrance of Optic Nerve.
  Fig. 2.—Lachrymal Gland.
Plate 79.—Eyelid. General View of Eyelid.
Plate 80.—Organ of Hearing.
  Fig. 1.—External Auditory Canal.
  Fig. 2.—Cochlea.

(A) THE HISTOLOGY OF CELLS AND TISSUES.

I. THE CELL.

The **cell** is the ultimate unit of a living organism. Every living organism originates from a cell. The protozoa consist of a *single* cell, while the metazoa are *multicellular*. The cells of the metazoa are structurally and functionally differentiated, cells having similar structure and similar function being united into larger divisions known as *tissues*.

Multicellular organisms, when fully developed, consist, however, not only of cells, but also of *cell-products*. The cells are therefore to be regarded as the *primary elementary constituents* of more highly developed organisms, the *secondary elementary constituents* being the excretory or transformation products of cells. In this latter category we may place the fluids of the body, as well as the ground substance, the cement substance, certain cuticular formations, granules, and especially fibers and fibrils. The essential difference between the primary and secondary elements of the body is that the primary elementary constituents, the cells, are capable of independent proliferation, while secondary elementary constituents have no such power. Excretion or transformation products can take their origin only from the cellular elements. A new cell may originate from a cell, but a new fiber cannot originate from a fiber.

The *form* of the *cell* is manifold. The spherical form may be regarded as fundamental, since it is the form presented by the *ovum,* the cell from which all other cells of the multicellular organism develop. The first embryonal cells which arise from the division of the impregnated ovum generally present the spherical form. This fundamental form of the cell, however, presents many variations, according to the position and function of the differentiated cells.

The *size* of the cell is subject to many variations analogous to those of the form. The smallest cells measure only 5 μ or less, while the largest are visible macroscopically, as for instance the large ova of many animals. The extreme size of such cells arises only through secondary deposition of food material in the cell-body. Most cells are microscopic, only a few, as the large nerve-cells of some animals, being visible with the unaided eye.

There are three essential or principal constituents of the cell: (1) The *cell-body* or the *protoplasm*; (2) the *cell nucleus*; (3) the *centrosome*. In addition to these, the cell may also contain other less important constituents. Certain cells have no nucleus and, when fully differentiated, no centrosome. Such cells, however, were originally nucleated (horny epithelial cells of the epidermis, red blood-cells of mammalia, central fibers of the lens). The non-nucleated condition represents, therefore, a state of senility, occurring only in highly differentiated cells no longer capable of division. (See pages 55 and 229.)

The **cell protoplasm** is an extremely complex albuminous substance and is the seat of the vitality of the cell. Many of the vital phenomena are not discernible even under a powerful microscope; on the other hand, life phenomena may manifest themselves in some form of *motion*.

This movement of the protoplasm may display itself under the form of the so-called *ameboid* motion, which consists of slow changes of form of the protoplasm, readily observed in the colorless blood-cells or leukocytes (see page 57), and may result in a locomotion of these cells. By the extension of processes of the leukocytes, so-called pseudopodia, these cells may not only move, but also take up solid substances such as particles of dust, bacteria, etc.; two processes surrounding the solid body may flow together and thus inclose the foreign body in the cell.

In other cells certain differentiated portions of the protoplasm are endowed with motion, as the *cilia* of ciliated cells and the *flagella* of the spermatozoa. In contradistinction to the ameboid movement, the *ciliary motion* is continuous and follows a certain law, in that the cilia move always in a certain direction and create a continuous ciliary current.[1]

The *cell protoplasm* presents a very complex *structure*, concerning which, even at the present time, the views of writers are widely at variance. According to the view now most generally accepted, protoplasm presents a *fibrillar* structure, the fibrils varying in size and arranged in the form of a reticular network; this is readily demonstrated in many cells. These fibrils of the protoplasm constitute the *mitom*, *spongioplasm*, or the *fibrillar mass.* Within this thread-like structure, which is visible only with high or with very high magnification, are scattered minute granules, observed more especially at the nodal points of the network; these are known as *microsomes.* That portion of the cell protoplasm not occupied by the fibrillar structure and the microsomes must be regarded as a fluid or semi-fluid substance, the *interfibrillar* substance, or the *hyaloplasm.*[2]

In addition to these structures which occur throughout the protoplasm, structures are often found which are to be regarded as inclosures or transformation products of the protoplasm. Thus, in many cells, especially in gland-cells at the time of secretion, are found larger or smaller granules, so-called *zymogen granules*, which are looked upon as products of metamorphosis of the protoplasm into the special secretion of the gland (see page 35). Most ganglion-cells contain in their protoplasm large granules or flakes, which show affinity to basic dyes, which probably also have to do with the metamorphosis of the cells and are known as *tigroid granules* (see page 73). Other cells contain in their protoplasm a varying number of *fat droplets*, which at times may fill the greater portion of the cell, as in the cells of adipose tissue (see page 52). The drops of sebum in the sebaceous glands of the skin show a similar relation, since in their formation they lie in a protoplasmic meshwork. The meshwork of the protoplasm is, however, in this case secondary; it develops only through the formation of the secretion.

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[1] The so-called molecular motion, a dancing motion of fine granules in fluids, is not an active motion. It occurs in the protoplasm of the salivary corpuscles, dead, swollen leukocytes, and also in granules of India ink suspended in a fluid, etc.

[2] According to some observers, the protoplasm consists of granules, which, if arranged in rows, may form threads. According to an idea which is accepted by few and is scarcely worthy of belief, the protoplasm is composed of separate honeycomb-like spaces (foam theory).

Other cell inclosures are the *pigment granules;* these are smaller or larger granules, generally yellow, brown, or black in color, and of irregular form. Now and then crystalloid structures occur in the protoplasm of many cells, known as *crystalloids* or protein crystals, and may result from the crystallization of the albuminous substance. (See Plate 4, Fig. 2.) Such structures have been observed in man in the epithelium of the lens and in the interstitial cells of the testis.

The outermost layer of the cell protoplasm, in which the mitom threads are generally coarser and more closely woven, frequently becomes condensed to form a special structure, known as the *cell membrane;* this can, in typical cases, be separated from the cell. It is generally structureless. In some instances the peripheral, differentiated layer of the protoplasm of the cell gradually changes to the ordinary protoplasm. In these cases we speak of a *crusta.*

The **cell nucleus** is a vesicular structure of very variable shape, lying in the interior of the cell. As a general rule, the form of the nucleus accommodates itself to the form of the cell; thus very long, narrow cells have elongated nuclei. The most varied forms of nuclei are, however, met with; they may be nearly or quite spherical, many are ellipsoid, and in certain cases they are distinctly lobulated or ring-shaped, or the nuclei are indented or compressed on one or several sides, so that a polynuclear effect may be produced. In certain cases two or more nuclei may be found in a *single* cell (in many leukocytes, giant-cells of the bone-marrow, occasionally in liver-cells, ganglion-cells, etc.). The nucleus is essentially the *reproductive organ* of the cell. Non-nucleated cells (see page 18) are therefore incapable of division. The cell nucleus contains complex chemical constituents, which, according to their reaction to staining reagents, are divisible into two classes, known as the chromatic and the achromatic nuclear constituents. The most important of these chemical constituents of the nucleus is the *chromatin*, chemically nuclein,[1] which is regarded as that portion of the cell which transmits the hereditary characteristics. It presents itself in different forms according to the state of activity of the nucleus (see page 22); usually, however, in the form of strands or threads, which frequently anastomose and show thickenings at the nodal points. The chromatin is supported by the achromatic substance, the *linin*, which, in the form of very fine threads, forms a dense network in the interior of the nucleus. In this network we find the true nuclear corpuscles or *nucleoli*, which consist of a chromatic substance (chemically not nuclein, but paranuclein). The nucleus is always, except during the process of nuclear division, surrounded by a *nuclear membrane*, consisting of an achromatic substance, amphipyrinin. The space within the nuclear membrane in the meshes of the linin network is filled with fluid, the *nuclear sap.*

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[1] The essential vital properties of the chromatin are not necessarily united to the (chemical) nuclein, since nuclein is found in portions of the body where there is no chromatin. The chemical and the anatomic concepts of nuclein are not identical.

The **centrosome**, the third constituent of the cell, represents the *dynamic center of the cell* in the processes of cell division. In the resting cell it appears as a single or as two punctiform structures, which are probably generally less than 1 μ in diameter. Since the centrosome is so small and so difficult to find, it has not yet been possible to demonstrate it in all the cells of the human body. We need not, however, on this account doubt its existence. In many animal cells (ova) centrosomes are often found of considerably greater size. The centrosome often lies in a small clear area of protoplasm, now and then showing fine radiate lines. This structure often becomes prominent only at the time of cell division.

PROLIFERATION OF CELLS.

Complex processes affecting more particularly the nucleus manifest themselves during the proliferation of cells. The division of the cell-body is without exception preceded by *division of the nucleus;* the former may even fail to take place and the process then results in the formation of cells having several or many nuclei. Structures which develop in this way and have numerous nuclei in a common protoplasm are known as *syncitia* [1] or *plasmodia.* Thus the transversely striated muscle-fiber is a syncitium. In normal human tissues probably all cells divide by what is known as *indirect cell division, karyokinesis,* or **mitosis**, in contradistinction to a less important type designated as direct or amitotic cell division.

A number of phases or stages are usually distinguished in the complicated process of mitosis. The first is the so-called skein stage or prophase; this is followed by the second stage, that of the equatorial plate or monaster; third, the stage of metakinesis; fourth, the stage of the daughter stars or diaster, the metaphase; fifth, the phase of the daughter skeins, the anaphase; sixth, that of the daughter nuclei, the telophase.

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[1] Many authors use the term syncitium to denote a structure arising from the fusion of several cells, and plasmodium to denote forms arising from the division of the nucleus without any subsequent division of the cell.

The structural changes manifested in the several phases of mitosis are essentially as follows:[1] The nucleus of the cell engaged in the preparatory stages of cell division presents a peculiar rearrangement of its *chromatin*, which begins to be grouped into distinct *filaments*. This arrangement becomes more and more definite, until gradually a certain number of distinct single threads are found. These distinct chromatic threads are known as *chromosomes*. The number of chromosomes is constant in the mitotically dividing cells of each species of animal. In the higher animals the number twenty-four predominates, while many lower animals have only four and some only two. In certain cells these chromosomes are very short, in some cases even granular in shape. It is not absolutely certain whether this constancy of the number of chromosomes prevails in the cells of all human tissues, although theoretically this ought to be the case.

The chromosomes usually appear in the form of loops; that is, each chromosome is bent at the middle at an angle. The scattered chromosomes now form a *close skein* (spirem), in which the loops are, as a rule, so arranged that the closed portion of the loop points toward one point of the periphery of the nucleus, the so-called *pole field*, while the free ends of the loops point in the opposite direction, the *antipole field*. At this stage the centrosome, which remained at rest during the condition of labile equilibrium of the cell, becomes active, assumes a position in the pole field of the spirem, and appears to send delicate rays in all directions. In the stage of the *loose skein*

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[1] The process is not quite the same in all mitoses. The variations which occur are, however, unessential.

PLATE I.—MITOSIS.

FIGS. 1-10.—**Ten Stages of Indirect Nuclear Division (Mitosis) from the Oral Epithelium of the Larva of a Salamander.** × 500.

Technic: Chromic acid solution, 2 per cent. Hematoxylin and eosin.

Fig. 1.—Cell with resting nucleus a short time before the beginning of the mitosis. The nucleus shows distinct, irregularly contoured threads.

Fig. 2.—The nucleus of the cell is at the beginning of mitosis. Distinct chromatin loops (chromosomes) are recognized. Stage of the close skein.

Fig. 3.—The nuclear membrane has disappeared. In place of the nucleus lies a loose skein of chromosomes (the pole field is at the left).

Fig. 4.—Mother star (monaster) viewed from above.

Fig. 5.—Mother star (monaster) viewed from the side. The chromosomes, except two, are grouped around the equator of the achromatic spindle.

Fig. 6.—Mother star viewed from the side. The chromosomes crowded closely around the equator of the spindle.

Fig. 7.—Stage of metakinesis. One-half of the longitudinally divided chromosomes is drawn toward each pole of the spindle.

Fig. 8.—Beginning constriction of the cell-body. Stage of the daughter star (diaster).

Fig. 9.—Completion of cell division. Transformation of the daughter stars into skeins (dispirem).

Fig. 10.—Change of skeins into resting daughter nuclei (complete daughter cells, telophase).

Reference letters: *c*, Centrosome; *ch*, chromosomes; *p*, polar rays; *sp*, achromatic spindle; x, scattered chromosomes.

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the arrangement of the chromosomes is still more distinct. These are now very regularly arranged and next undergo a *longitudinal cleavage* of such a kind that each chromosome is divided longitudinally into two daughter chromosomes, which, however, for a variable time remain in close apposition, and for this reason this longitudinal division is not observed at this time unless the magnification is sufficiently high. At the same time, the nuclear membrane disappears and the nuclear fluid mingles with the cell protoplasm; the cell has no longer a circumscribed nucleus. The centrosome, in case the resting cell did not contain two, now divides into two halves, which move apart, and a small *achromatic spindle* can now be recog-

Tab. I.

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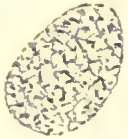

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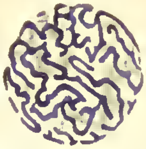

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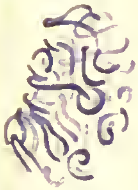

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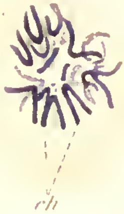

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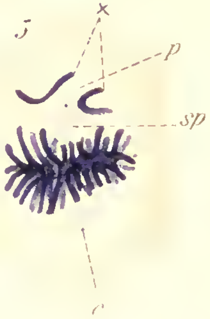

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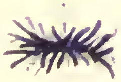

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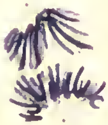

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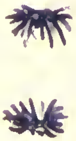

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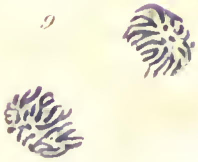

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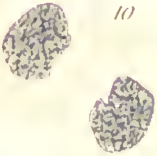

nized between them; this enlarges as the centrosomes continue to move apart. This is the anlage of the so-called *central spindle* or the uniting filaments, a portion of the achromatic spindle, which forms an essential portion of the figure of mitotic cell division. There are further developed rays, which pass out from the centrosomes in opposite directions toward the periphery of the cell; these are known as polar rays. The origin of this achromatic spindle is not as yet fully established. It would seem probable, however, that the linin network of the nucleus contributes to the formation of the structure.

While the spindle, the poles of which are formed by the centrosomes, is still further increasing in size, the chromosomes arrange themselves about the equator of the spindle in nearly *one* plane, the *equatorial* plate. This stage is designated as that of the mother star, or monaster. The dividing cell is now easily distinguished from the resting cell. In place of the nucleus a clear area is found, in which may be observed the mother star, or monaster, so named because, when viewed from one pole, the chromosomes form a star-like figure. Besides the fibers of the central spindle, another system of fibers develops—that of the *traction fibers* or mantle filaments. These are generally finer than those of the central spindle and are present in greater numbers. They run from the centrosomes to the chromosomes and attach themselves to each of the latter in such a manner that the fibers coming from one centrosome insert themselves into the adjacent half of the loop. In the mechanism of mitosis these fibers are believed to play a part in the processes of metakinesis which now follow; they draw apart the halves of the loops toward the opposite poles of the spindle. *Metakinesis* begins when, in the equatorial plate, the longitudinal cleavage of the chromosomes is very distinctly seen; the interspace between two daughter chromosomes becomes gradually greater, a change in the whole mitotic figure going hand in hand with this process. A *double* *star* or *diaster* develops, each daughter star moving gradually nearer to its pole. At the same time a perceptible elongation of the cell-body in the direction of the long axis of the spindle takes place.

The two daughter stars are connected by achromatic fibers, the so-called *uniting fibers.* These are probably the remains of the central spindle and in the center of their course often show thickenings called *central spindle corpuscles,* which mark the place of the future division of the cell. Even in the diaster stage the remains of the traction fibers still run from the chromosomes to the centrosomes, but seem to become shorter and shorter the farther the daughter stars are separated from each other.

When the daughter stars are farther separated, the *division of the cell-body* begins by a gradual ring-shaped constriction of the cell near the middle (metaphase). When the constriction is nearly completed, a change of the daughter stars into skeins begins. Just as the mother star was formed from the skein, so now a skein is formed from each daughter star, and there is developed a mitotic figure known as the dispirem. At the same time the remains of the former spindle and the polar rays degenerate (anaphase).

After the division of the cell-body is completed, a nuclear membrane is formed around each of the *daughter skeins,* and the new nuclei—daughter nuclei—are formed. The changes involved in this process, the alterations of the chromatin, etc., are collected under the term telophase. The division of the centrosome of each daughter cell may now take place (see page 22).

When the indirect nuclear division is completed, each of the daughter cells has received half of the cell-body of the mother cell, half of the nucleus,—that is, half of each chromosome,—and half of the centrosome, or one of the two centrosomes now and then present in the resting cell. Each daughter cell is therefore a counterpart of the mother cell.

Segmentation of the impregnated ovum also occurs after the manner of mitotic division; in this case, however, half of its chromosomes are supplied by the spermatozoon, the male pronucleus, and half by the female pronucleus, the nuclear constituents of the matured ovum. It is not always true that the resultant cells of a mitotic nuclear division are of equal size. In the processes of maturation of the ovum, an unequal division of the protoplasm takes place, since the polar body, one of the division products, is very much smaller than the other, the egg-cell. In the formation of the second of the two polar bodies a reduction of the chromatin takes place, since the longitudinal cleavage is omitted and the number of chromosomes is reduced one-half.

In many tissues of the human body, cell division takes place *continually*, as in the germ centers of the lymphoid tissues (see page 121), in the tubular glands of the intestines, and in the deeper layers of the epidermis. Other cells of the human body, on the other hand, have a very long life, so far as we know. Ganglion-cells, the majority of gland-cells, many epithelial cells, probably exist during the whole life and never show the phenomena of cell division. In cold-blooded animals, in which it is possible to make observations during the life of the animal, the time of a mitosis has been established at six to eight hours; in the warm-blooded animals the process is probably completed in less than an hour.

The **secondary elementary constituents** of the human body may be present in the form of *fluids*, regarded as the excretory products of the cells. The plasma of blood and lymph, intercellular fluid, the synovial fluid and serous fluids of bursæ, joint cavities and body cavities may be mentioned under this head. If the excretory product of the cell is semi-fluid or more or less solid we speak of *ground substance* or *cement substance*, the latter when the intercellular substance is found between the cells in small amount, as in epithelial tissues, the former when the amount of intercellular substance is predominant, as in cartilage, bone, etc. *Membranes* and *cuticular formations* arise on the surface of cells which are arranged in rows, such as epithelia, through excretion from these and hardening of the excreted membrane, so that each cell does not have a crusta or membrane, but a common membrane develops, which can be isolated. A typical example of such a membranous formation is the lens capsule. Whether the membrana propria of glands is to be regarded as an excretory product of gland-cells is still open to discussion. Structureless membranes may arise from the fusion of cells, during which process the nuclei of such cells may or may not disappear. Membranes may also arise from the fusion of fibers, the so-called fusion membranes. Elementary *fibers* or fibrils are very widely distributed; they arise for the most part as direct transformation products of cells (according to some investigators, from the homogeneous ground substance). They occur as the fibrillar elements of the connective tissue (the connective-tissue fibers), of the elastic tissue (the elastic fibers). In the muscular tissues elementary fibrils occur as muscle fibrillæ and in nerve-cells and nerve-fibers as neurofibrils and as neuroglia fibers, the supporting tissue of the central nervous system.

II. THE TISSUES OF THE HUMAN BODY.

The meaning of the term tissue cannot be defined without qualification. In general we designate as tissues those structures which are composed of equal or similar cells arranged in a certain definite order and possessing a similar function. By a strict interpretation of the histogenesis of tissues we are forced to recognize but two chief types: (1) The epithelial tissues; (2) the connective tissues (mesenchyme). Basing our subdivision on a functional differentiation of these two chief types of tissues, we may recognize two other divisions; these are the muscular and the nervous tissues; the latter is of epithelial origin, the former probably only partially so, the striated muscle-fibers arising from epithelial cells, while the smooth muscle-fibers are probably without exception of mesenchymal origin.

It is customary, therefore, to recognize in the fully developed human body four types of tissues: (1) The epithelial tissues; (2) the supporting tissues or the connective tissues; (3) the muscular tissues; (4) the nervous tissues.

EPITHELIAL TISSUE.

Epithelial tissues consist of clearly defined, regularly arranged cells, which clearly show their cellular nature and which are separated by very small amounts of intercellular substance. Aside from the occasional cuticular formations, they give origin to no other secondary constituents, and especially not to fibrous elements.

Epithelial tissue covers the whole surface of the body and all mucous membranes and forms the essential portion of all glands of the body.

According to the form of the elements, we distinguish squamous, cubic, cylindric, pyramidal or prismatic, and irregular epithelial cells; epithelial cells which have cilia are designated as ciliated epithelial cells, independently of the form of the cells. Epithelial cells may be arranged in a single layer or in several layers, so that we distinguish simple and stratified epithelium. We also distinguish a condition in which the main portion of the cells with the nuclei lie in different planes, while fine processes or thinner portions of the cells extend to the superficial surface as well as to the base of the epithelium; such epithelium is known as pseudo-stratified, and it is often difficult to determine whether we have stratified epithelium or one presenting several rows of nuclei.

According to the form and arrangement of the epithelial cells, we distinguish different types of epithelia. In the human body the following types are recognized:

PLATE 2.—EPITHELIAL TISSUES.

FIG. 1.—**Portion of the Great Omentum of a Rabbit, the Cell Outlines Being Blackened by Silver.** × 280.

The figure shows two layers of a simple pavement epithelium (peritoneal mesothelium). The cell boundaries are black, nuclei are stained blue.

Technic: Silver impregnation. Hematoxylin.

Reference letters: k_1, Nuclei of superficial epithelial layer; k_2, nuclei of deeper epithelial layer.

FIG. 2.—**Stratified Squamous Epithelium from the Human Mouth.** × 280.

The preparation was taken from one who had been executed.

The figure shows the typical structure of stratified squamous epithelium, with indentations of the basal layer caused by low papillæ of the mucosa. The deepest layer is cylindric, the most superficial layers are of flattened cells. All the transitional forms are found between them. In the deeper layers mitoses are seen; leukocytes are found scattered through the entire thickness of the epithelium.

Technic: Müller's fluid. Hematoxylin-eosin.

Reference letters: *l*, Leukocytes; *m*, mitoses; *p*, papillæ.

FIG. 3.—**Cylindric Epithelium from the Human Intestinal Tract.** × 420.

The preparation was taken from one who had been executed.

The figure shows at the left three isolated cells from the intestinal epithelium and at the right a number of the same kind of cells, which are still attached. All the cells present on their superficial surface a striated cuticular border. Leukocytes are found among the cells, and some of them are acidophile.

Technic: Potassium bichromate and formalin. Hematoxylin-eosin.

Reference letters; *l*, Leukocytes; l_1, eosinophile leukocytes.

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1. Simple flattened or squamous epithelium, consisting of a single layer of epithelial cells which are generally irregularly polygonal. Occurs as the epithelium of the serous cavities (mesothelium), of the alveoli of the lungs, of certain regions of the inner ear, and the intercalary portions of many gland-ducts.

2. Simple cubic epithelium. Occurs as the epithelium covering the choroid plexus of the brain, that of the lens capsule, of the middle ear (frequently with cilia), of numerous glands and excretory ducts of glands.

3. Simple columnar epithelium. Occurs as the epithelium of the entire intestinal canal, of the gall-bladder, of many gland-ducts.

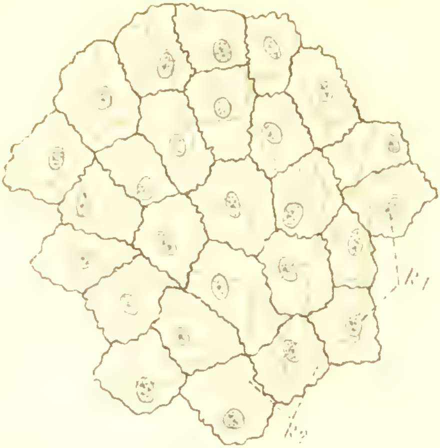

Fig. 1

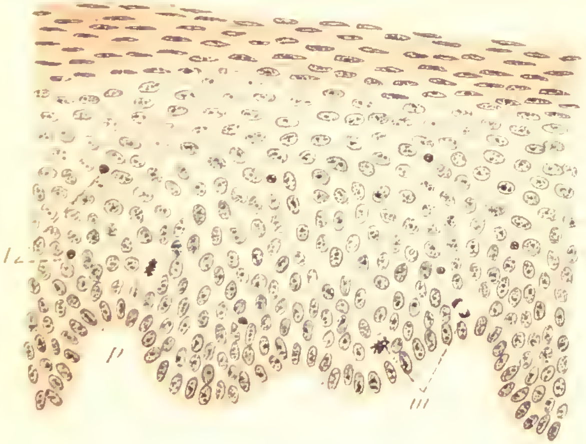

Fig. 2

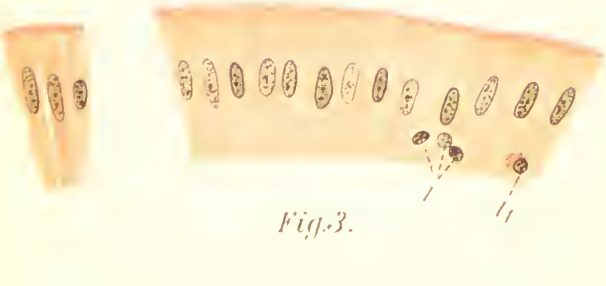

Fig. 3.

4. Simple ciliated epithelium. Occurs as the epithelium of the uterus, of the oviduct, of the finer bronchial branches of the lungs, of the accessory cavities of the nose, of the middle ear, and the epithelium of the central canal of the spinal cord.

5. Stratified pavement or squamous epithelium. This terminology is inappropriate, as only a varying number of the superficial layers consist of flattened cells, the cells of the middle layers being polyhedral and those of the lowest layers columnar. As a rule, the basal surface of this variety of epithelium is not smooth, but indented by the papillæ of the connective-tissue layer which lies below. Stratified squamous epithelium has a very wide distribution, occurring as the epithelium of the skin, the so-called epidermis, in which the upper flattened layer is horny, the epithelium of the mucous membrane of the mouth, pharynx, vocal cords, esophagus, of portions of the conjunctiva bulbi, of the external auditory passage, of the vagina and the female urethra, and the terminal portion of the male urethra. The epithelium of the cornea consists of several layers of cells, only a few of which are flattened, and rests on connective tissue without papillæ. The epithelium of the Graafian follicles of the ovary also simulates the stratified squamous epithelium.

6. Stratified columnar epithelium has a limited distribution. It occurs in the larger excretory ducts of many glands, especially the salivary glands, in the male urethra, and on the conjunctiva palpebrarum.

7. Stratified ciliated epithelium. Its superficial cells are prismatic and show cilia; between their narrow ends are found broad fusiform cells, and in the deeper portion near the basal surface of the epithelium, rounded or pyramidal cells. This epithelium has a wide distribution, lining the entire respiratory tract—the nasal cavity, the upper portion of the pharynx and the Eustachian tube, the greater part of the larynx, the trachea and all the larger bronchi; also the vas deferens and the ductus epididymidis; the latter has an especially tall columnar epithelium, with very long, coarse cilia; beneath and between the tall columnar cells is a single layer of pyramidal cells.

8. *Transitional epithelium.* This is the epithelium of the urinary passages and may be regarded as a modified squamous epithelium, the uppermost layer of cells being especially characteristic. The cells of this layer are large, often polynuclear, flattened cubic, and have on their lower surface several depressions for the cells of the next lower layer. The upper portions of these cells of cubic or prismatic shape are somewhat rounded and fit into the depressions in the under surface of the superficial cells. Then follow one or two layers of irregularly rounded cells, and below these, low columnar cells. This epithelium occurs in the pelvis and calices of the kidney, in the ureter and bladder. Transitional epithelium is capable of extreme distention. In the bladder the form of the cells changes considerably, so that in the empty condition the superficial cells are cubic or almost columnar, while in the distended condition they are nearly flat.

The epithelium of the tubules of the testes assumes an especial arrangement, the form of which is very variable and is dependent on the function. (See page 175.)

The Relations of the Epithelial Cells to Each Other.—Between epithelial cells, united to form *epithelium*, there is found a variable, though always small amount of cement substance, which can be blackened under special treatment with silver nitrate solutions. Frequently, especially in pavement epithelium, there is observed an interlocking of the intercellular bridges, serrated borders of contiguous cells. (See Plate 2, Fig. 1.) In certain epithelia, especially the middle layers of the stratified squamous epithelium, contiguous cells are united by fine, bridge-like, protoplasmic processes, so-called *intercellular bridges*. These stand in relation with the fibrillar substance of the cell. It is not yet established how widely distributed such intercellular bridges are; but it is doubtful whether they are found between all epithelial cells.

Near the surface, especially of the columnar epithelium, the cement substance becomes condensed, being thus differentiated from the deeper semi-fluid cement. These firmer bands of cement are called *terminal ledges.* The terminal ledges form a perfect network, in the meshes of which the tops of the epithelial cells fit.

The epithelial constituents of glandular tissue are known as *gland-cells.* Their form differs in different glands, the cubic form predominating. This type of epithelium will be more fully considered in connection with the various glands to be discussed.

Special Differentiation of Epithelial Cells.—Under this heading we may consider primarily the motile appendages of certain epithelial cells, the so-called *cilia* or *flagella.* These consist of protoplasmic contractile fibers, which are placed on the free surface of the cells constituting the ciliary border. Careful investigation of the ciliated epithelium has shown that each cilium arises from a small nodule situated at the upper end of the cell near the free border. *Cuticular borders* are found in the form of striated structures situated on the free surface of columnar cells, especially of the intestine. This striated border probably consists of small rod-like structures arranged in a row. The epithelium of certain portions of the uriniferous tubules presents a striated border, the so-called *brush processes* of the cells; these are known to be made up of short rods. It is probable that similar structures are also to be found on the surface of the epithelial cells of the olfactory mucous membrane. A *striation* of the *basal* portion of the cells is seen in the cells of the excretory ducts of many salivary glands and in certain epithelial cells of the kidney. Epithelial cells may show a large number of different kinds of *cell-inclosures,* as *fat, pigment, crystalloids.* Other peculiarities of epithelial cells depend upon their *secretory* activity. Not only do the gland-cells func-

PLATE 3.—EPITHELIAL TISSUES.

FIG. 1.—**Transitional Epithelium from the Human Ureter.** × 450.

The preparation was taken from an individual who had been executed.

The figure shows the epithelium in the collapsed or slightly distended ureter. At the right is a polynuclear surface cell; the uppermost layer of the mucosa is seen under the epithelium.

Technic: Absolute alcohol. Hematoxylin-eosin.

Reference letters: *1*, Surface cells; *2*, middle cellular layer; *3*, lower layers of cells; *c*, capillary vessels of the mucosa.

FIG. 2.—**Stratified Ciliated Epithelium from the Regio Respiratoria of the Human Nasal Mucous Membrane.** × 500.

The preparation was taken from one who had been executed.

The figure shows the usual picture of the stratified ciliated epithelium with the high prismatic cells and the basal and replacement cells.

Technic: Zenker's solution. Hematoxylin-eosin.

Reference letters: *b*, Basal cells; *c*, columnar cells; *e*, replacement cells; *f*, cilia.

FIG. 3.—**Ciliated Epithelium of the Ductus Epididymidis of Man.** × 420.

The preparation was taken from an executed individual.

The figure shows the peculiar two-layered epithelium of the ductus epididymidis, with the long, whip-like cilia on the surface cells.

Technic: Zenker's solution. Hematoxylin-eosin.

Reference letters: *c*, Cylindric cells; *r*, round basal cells.

FIG. 4.—**Pigment Epithelium of the Retina of the Cat.** × 280.

The quite regular polygonal cells are almost filled with pigment granules. The cell boundaries and the portion nearest to the nucleus appear free from pigment.

Reference letter: *k*, Nucleus.

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tionate as secreting or excreting cells, but also, to a certain extent, all superficially placed epithelial cells; especially is this true of the epithelial cells of mucous membranes. For this reason it is sometimes difficult to determine whether we have before us a true simple gland or a crypt or depression of the mucous membrane, since the cells of the latter may also possess the power of secreting.

The secretory activity of the epithelial cells is dependent wholly on the protoplasm, the secretions being products of metamorphosis of the protoplasm. The process of secretion is most easily recognized microscopically when it

Tab. 3.

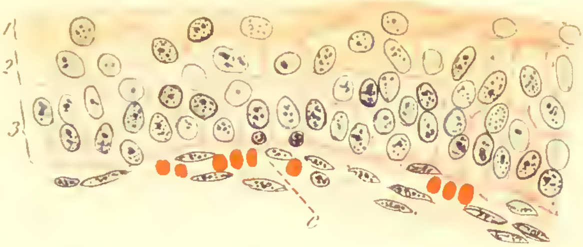
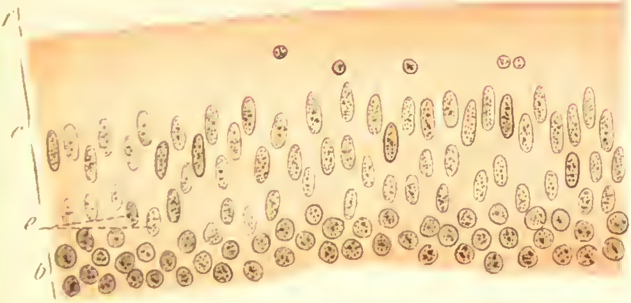


Fig. 1.



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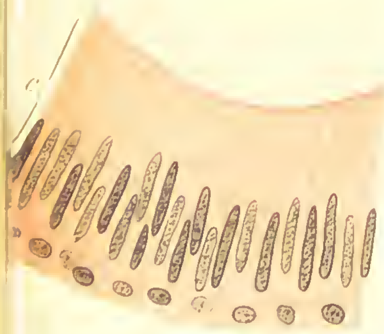


Fig. 3.

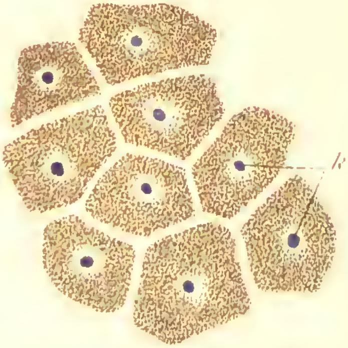


Fig. 4.

concerns the formation of *fat*, as in the mammary glands, or of the *sebum* of the sebaceous glands. In vacuoles of the protoplasm the secretion is seen in droplets, which are at first small, but gradually increase in size; either the enveloping border of protoplasm breaks down and the secretion is set free, as in the mammary glands, or, as in the sebaceous glands, the globules of secretion which formed separately in the protoplasm become confluent while the cell nucleus at the same time disappears and the entire cell disintegrates. This disintegration of the cells of the sebaceous glands represents the only instance in the human body in which the cells break down in the process of secretion. Goblet-cells now and then break down after the evacuation of their contents; however, the process is not necessarily connected with the secretion. The mucus-secreting cells, the so-called *goblet-cells*, have a wide distribution, being especially prevalent in the epithelium lining the respiratory passages and the intestinal canal. They may be regarded as *unicellular glands*. The secretion develops in the form of secretory granules, appearing in the protoplasm in the free portion of the cells and developed from the protoplasm. These granules enlarge and become confluent. Probably each cell of the intestinal epithelium may become a goblet-cell in that the portion of the cell lying next to the surface of the epithelium forms a mucous secretion from the protoplasm. The cell assumes the form of an open goblet just before secretion,—that is, after the cell membrane has ruptured, allowing the secretion to appear at the surface of the cell. After evacuation of the secretion, the cell may be restored to an ordinary epithelial cell. In other epithelia, for instance in the epithelium of the stomach, the formation of mucus seems to occur more simply, much as in the gland-cells of mucous glands. In many other epithelia, especially in many gland-cells, the secretory activity is manifested by the occurrence of *stainable granules* in the protoplasm, the so-called *zymogen granules*, which represent the preliminary stages of the formation of the secretion. The gland-cells, the secretion of which is not solid or semi-solid, as fat, sebum, mucus, but fluid, evacuate their secretions, not simply on the surface of the cells into the lumen of the gland, but also by means of *secretion capillaries.* These are fine, frequently anastomosing ducts, having no walls of their own; they may lie between the cells, where the walls are formed of groove-like depressions of the protoplasm of contiguous cells, known as intercellular secretory capillaries, as for instance the bile capillaries of the liver; others extend into the protoplasm of cells, intracellular secretory capillaries, as in certain cells in the glands of the fundus of the stomach.

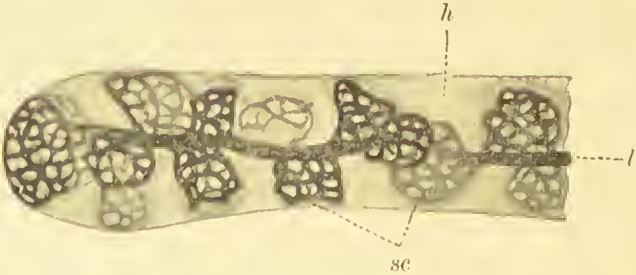


Fig. 1.—Portion of the mucous membrane of the fundus of the human stomach, treated by the Golgi method. × 420. The figure shows very distinctly the intracellular secretion capillaries. *l*, Lumen of the gland ; *sc*, secretion capillaries of the parietal cells ; *h*, chief cells (single cells not visible).

Another special differentiation is seen in the *cornification* of the cells of the superficial layers of the epidermis (see page 202). Cornification is usually accompanied by loss of the cell nucleus, but the cell is preserved. Cornification is preceded by a granular condition of the cell protoplasm, the cells containing at this stage the so-called *eleidin* or *keratohyalin* granules (see page 203). These granules develop into the keratin of cornified cells.

Epithelial tissue itself contains no blood-vessels, but between the cells there are often found the terminal branches of nerve-fibers. The epithelium is nourished from the underlying layer of connective tissue. Capillaries, however, frequently come in direct contact with the epithelial cells in certain glands where the original type of epithelial arrangement is disturbed, as for instance in the liver (see page 162), where the blood capillaries lie directly against the epithelial cells.

Forms of Glands.—Although glands are to be regarded as organs, yet it seems advisable to discuss here the forms of glands which occur in the human body. The glands are named partly according to their function (salivary glands, sudoriferous glands, sebaceous glands) and partly according to their position (intestinal glands, thyroid).

The *form of the secretory acini*, or of the blind terminal portions of the glandular system, is the determining factor in the classification of glands. Taking this factor into consideration we distinguish two main classes of glands: (1) *Tubular*, when the terminal portions have the shape of tubes; (2) *alveolar* or acinous, when the terminal portions are spherical or sac-like. There are certain transitional forms between these two main types, since the tubular terminal chambers of many glands may show sac-like enlargements at their blind extremities and similar enlargements at their sides; these are known as tubulo-alveolar glands.

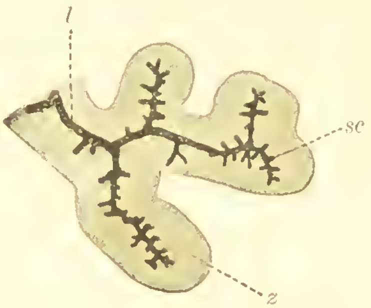


Fig. 2.—Portion of the human pancreas treated by the Golgi method. × 375. The figure shows short, intercellular secretory capillaries. *l*, Lumen of a gland tubule; *sc*, short secretion capillary; *z*, gland-cells (the single cells are not visible).

By far the greatest number of the glands of the human body are tubular, or, more correctly stated, tubulo-alveolar. In the simplest form, tubular glands occur as *simple unbranched tubules*, as in the glands of the intestine (see page 128); simple unbranched glands are, however, found with the terminal portion *coiled into a skein*, as the sudoriferous or coil-glands of the skin. Other tubular glands show a branching, especially toward their blind ends. The glands of the fundus of the stomach and of the uterus present this peculiarity to a slight degree, and the glands of the pyloric region of the stomach to a greater degree.

Other tubular and tubulo-alveolar glands are much *branched*,—that is, a larger number of greatly convoluted tubules empty into a *distinctly differentiated common duct*,—giving rise to a so-called *system of ducts* (see schemes 3, 5). This class comprises the duodenal glands and many small glands of the oral cavity, of the pharynx, of the esophagus, of the trachea, of the bronchi, of the nasal mucous membrane, and of the urethra. Very many, and these the largest of the tubular glands of the human body, are *compound* glands and consist of many systems of ducts; into one large common duct several smaller ones open, each of which again receives several tubular terminal divisions of the gland. This category comprises all the medium-sized and larger salivary and mucous glands, the mammary gland, the lachrymal gland, the kidney, and most of the glands of the genito-urinary apparatus, as the prostate gland, bulbo-urethral and vestibular glands. The testes, and especially the liver, represent compound tubular glands, the tubules of which constantly anastomose. On this account they are called *reticular* glands.

The *alveolar* glands are much less widely distributed than the tubular glands. Alveolar glands which consist of a single sac-like terminal chamber do not occur in man, unless the ovary may be classed under this head. On the other hand, branched alveolar glands consisting of one system of ducts are frequently met with, as for instance the sebaceous and Meibomian glands. In the human body the *one compound* alveolar gland, consisting of several systems of ducts, is the lung.

There are glands without excretory ducts, as the thyroid. These probably pour their secretion into the blood- or lymph-vessels (so-called *internal secretion*). The ovary empties its secretion, the ova, through the ruptured gland follicles. The alveoli of glands consist, in addition to the gland-cells, of a generally structureless membrane sur-

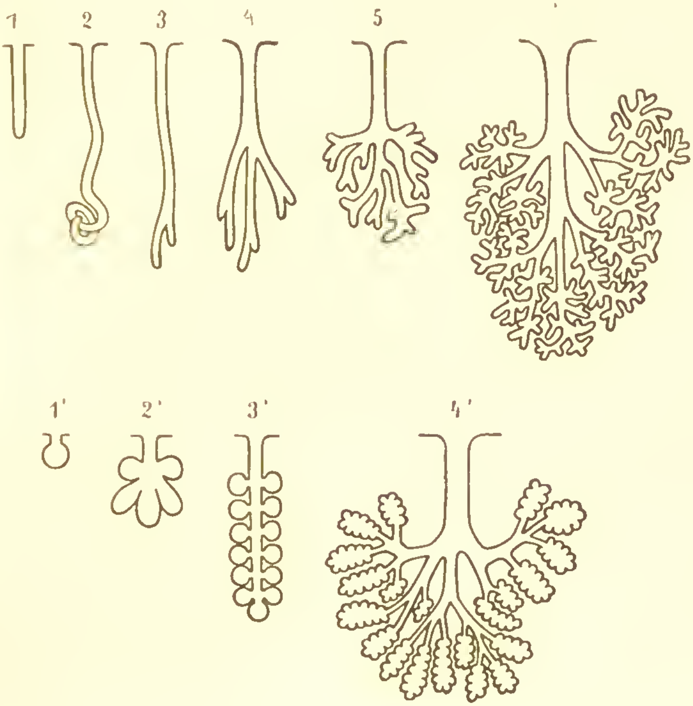


Fig. 3.—Diagrammatic representation of the forms of human glands: *1*, Straight, unbranched, simple tubular gland; *2*, unbranched, simple tubular gland, convoluted at the extremity; *3*, simple tubular gland forked near the extremity; *4*, simple tubular gland, showing several branches; *5*, tubular gland, showing many branches (system of ducts); *6*, compound tubular gland; *1′*, simple alveolar gland consisting of one alveolus; *2′*, simple gland consisting of several alveoli; *3′*, simple gland consisting of many alveoli; *4′*, compound alveolar gland.

rounding the gland-cells, the so-called *membrana propria*, which probably represents a membrane formed by the fusion of connective-tissue cells (according to others, a membrane formed by secretion of the epithelial cells). Occasionally the membrana propria contains nuclei, a fact which contraindicates a secretory origin. Other glands, as the sudoriferous glands, have a layer of smooth muscle-fibers between the glandular epithelium and the membrana propria.

While the gland-cells represent the parenchyma of glands, the interstitial tissue or stroma is formed of loose connective tissue, which fills the interspaces between the gland tubules, etc., and contains the blood-vessels and nerves of the gland.

THE SUPPORTING OR CONNECTING TISSUES.

The entire group of connective tissues, forming an important part of the adult human body, has a common histogenesis.

All forms of connective tissue develop from the mesenchyme, which is not present at the time when the blastoderm consists of the three germ layers, the ectoderm, mesoderm, and entoderm. It develops secondarily by cleavage (separation of single cells in certain regions) from the middle germ layer or mesoderm, which then differentiates into an epithelial portion, the mesothelium, and a connective-tissue portion, the mesenchyme. The latter, at its first appearance, consists of quite uniform branched cells, the embryonal connective-tissue cells. Later, however, manifold differentiations occur, so that it becomes necessary to recognize a great number of subdivisions of the connective tissues. In comparison with the epithelial tissues, connective tissues are characterized by the fact that the secondary elementary constituents, ground substance and fibers, predominate, while the cells in the majority of connective tissues are less prominent.

In the various types of connective tissues the following elements may be recognized: (1) *Cellular elements,* the connective-tissue cells, or, as formerly designated, the connective-tissue corpuscles, with the aberrant forms of cells; (2) *fibers* or fibrillæ; these are divided into white fibrous tissue-fibers, reticular fibers, and elastic fibers; (3) *ground substance.*

The **cells** of the different subdivisions of connective tissues differ widely in shape and structure, although they all develop from mesenchymal cells. The cells of *gelatinous connective tissues* (see page 47) most nearly resemble the embryonic type and are connected by distinct processes. The cell-body of a connective-tissue cell is usually flattened and presents several or many protoplasmic processes; stellate forms are frequently met with, and now and then cells of polygonal form. The processes of neighboring connective-tissue cells frequently anastomose, as may be observed in the large and typically shaped connective-tissue cells of the *cornea.* In the majority of connective tissues the cells lie at relatively great distances from each other and are separated by large amounts of ground substance or fibrous tissue. While most connective-tissue cells are relatively small and flattened, certain varieties are characterized by their size and their abundance of protoplasm; to this class belong the so-called *interstitial cells* of the *testis* and ovary, the *plasma-cells* and *mast-cells* of ordinary connective tissue, the last of which show peculiar stainable granules (see page 59).

Marked variation from the general form of connective-tissue cell is seen in cartilage (see page 48), in adenoid tissue, and in adipose tissue. The cells of adenoid tissue known as lymphocytes are of spherical form, with relatively large, round nuclei. They stand in relation to certain cells of the blood, the so-called leukocytes (see under Blood, page 57). The cells of adipose tissue consist, for the most part, of large fat-drops, the nucleus and protoplasm of the cells being compressed and flat and crowded to the periphery of the fat-drop.

PLATE 4.—CONNECTIVE TISSUES.

FIG. 1.—**Reticular Connective Tissue from a Human Lymph-gland.** × 280.

The preparation was taken from an individual who had been executed.

The figure shows fine and coarser trabeculæ, which anastomose and form a reticular framework. Round or oval nuclei lie on the trabeculæ.

Technic: The preparation was made by shaking out the cells from a section. Hematoxylin-eosin.

Reference letters: *tr*, A larger trabecula.

FIG. 2.—**Interstitial Cells of Human Testis, with Crystalloids.** × 500.

The preparation was taken from one who had been executed.

The figure shows eight of the large connective-tissue cells rich in plasma, which are found together with the ordinary connective-tissue cells as the interstitial tissue of the testis. Four of the cells contain (one to three) crystalloids in longitudinal or cross-section. One cell has two nuclei.

Technic: Zenker's solution. Hematoxylin-eosin.

Reference letters: *kr*, Crystalloids; x, transversely cut crystalloids.

FIG. 3.—**Mast-cells from the Interstitial Connective Tissue of the Dog's Prostate.** × 500.

Besides the usual small cells, the figure shows four large connective-tissue cells, the cell-body of which is filled with basophile granules. The nucleus, on account of this fact, is not distinguishable.

Technic: Müller's fluid. Hematoxylin-eosin.

Reference letters: *m*, Mast-cells; *bdg*, nuclei of ordinary connective-tissue cells.

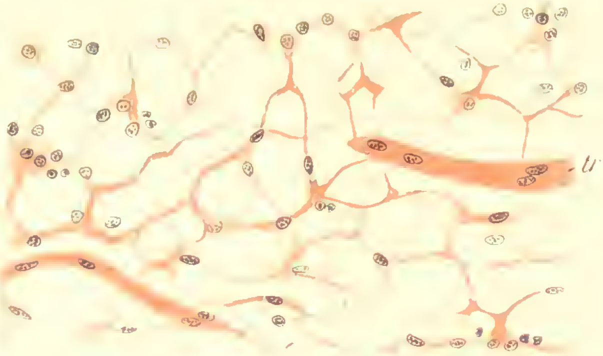
FIG. 4.—**Connective-tissue Cells from the Cornea of the Rabbit.** × 500.

The figure shows the large connective-tissue cells of the cornea with anastomosing processes.

Technic: Gold chlorid preparation. Formic acid.

The *endothelial cells* represent a special variety of connective-tissue cells (see also page 115). These are flattened cells, arranged like epithelium, and in many particulars resemble simple squamous epithelium, from which they differ genetically. Cement substance joins the cells, which are often arranged with great regularity and which, in a single layer, line the lumen of the blood- and lymph-vessels and occasionally other cleft-like spaces of connective tissue, as for instance bursæ, joint cavities, and anterior chamber of the eye.

Tab. 4.



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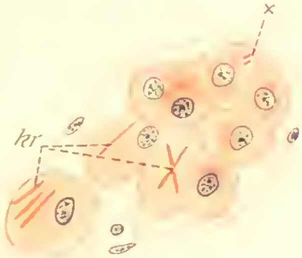

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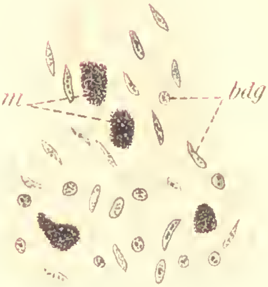

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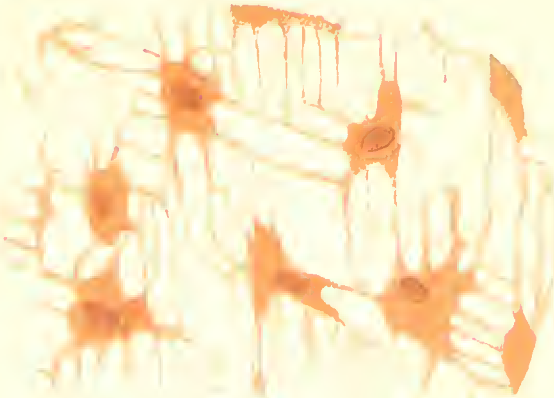

Fig 4.

The cells of connective tissue may contain several kinds of inclosures, as fat, pigment, crystalloids.

Three kinds of **fibrous elements** of connective tissue are recognized. These differ morphologically as well as chemically: (1) White fibrous connective-tissue fibers or fibrillæ; (2) reticular fibers or fibrillæ; (3) elastic fibers.

The *white fibrous tissue* fibrils are fine fibrous elements less than 1 μ in diameter, which yield gelatin on boiling (collaginous connective tissue). They rarely occur singly, but are very generally united into finer or coarser bundles by an interfibrillar cement substance. They dissolve in caustic potash and become swollen and transparent in acetic acid, so that under the microscope they are no longer discernible. They digest very slowly in pancreatin. *Reticular fibrils* resemble the fibrils of white fibrous connective tissue, but differ from them in that they do not yield gelatin on boiling. They are not digested in pancreatin.

The *elastic fibers* vary very much in thickness; the finest are scarcely larger than the connective-tissue fibrils, while the largest are as large as relatively large connective-tissue bundles. They are easily distinguished optically as well as chemically from the connective-tissue fibers. They are strongly refractive to light and resistant to alkalies and acids. Even the largest elastic fibers cannot be broken up into fibrillæ. They are composed of a delicate outer sheath, which does not stain in magenta, and an interior which stains deeply with this stain. They yield no gelatin on boiling, but they yield elastin. They are readily digested in pancreatin, less readily in pepsin. They occasionally form

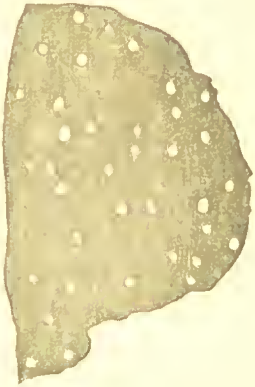

Fig. 4.—Elastic membrane from the human arteria basilaris. × 420.

fibrous networks, the meshes of which are so small that *elastic plates* result, possessing only small openings, which are called *elastic membranes* (Fig. 4).

The views of investigators pertaining to the development of fibrous elements of connective tissue are still at variance. Certain observers regard the fibrous elements as products of excretion or fixation of the ground substance.[1] This view is supported by unsatisfactory evidence. According to another theory, which is supported by many observations, the fibrous structures of the connective tissues, including the elastic fibers, arise from the connective-tissue cells themselves and in their protoplasm and later become independent.

The **ground substance** of the various connective tissues varies greatly; it may be fluid or semi-fluid, as in the blood and loose connective tissue, or it may have a solid consistence, as in cartilage and bone (see under this tissue, pages 48 and 81). Only rarely, as in many kinds of cartilage, do fibrous structures occur in the ground substance (here they are chemically identical with the ground substance). As a general rule, the ground substance of the various connective tissues is homogeneous.

According to the relation and morphologic characteristics of the cells or of the intercellular substance, the following groups and varieties of connective tissue are distinguished:

Group A—Characterized by the Fibers:

1. Simple fibrillar connective tissue.
2. Elastic tissue.

Group B—Characterized by the Ground Substance:

1. Gelatinous connective tissue.
2. Cartilage.
3. Bone.
4. Dentine.

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[1] In the ground substance of hyaline cartilage, fibrous formations of the ground substance occur, which are, however, chemically identical with the ground substance itself and take their origin from it.

Group C—Characterized by the Cellular Elements:

1. Adipose tissue.
2. Pigmented connective tissue.
3. Reticular and adenoid connective tissue.
4. Blood and bone-marrow.

The **simple fibrillar connective tissue** may be further subdivided into two classes, which are not very sharply defined: (*a*) Loose connective tissue; (*b*) formed connective tissue. In structure the two forms are almost alike. The differentiation rests on the manner in which the characteristic elements of the connective tissue fibers or fibrils are arranged. In loose connective tissue they are found in bundles of different size, having a slightly wavy course. Besides the bundles of connective-tissue fibers, loose connective tissue always contains elastic fibers of varying number and size, which can be easily distinguished from

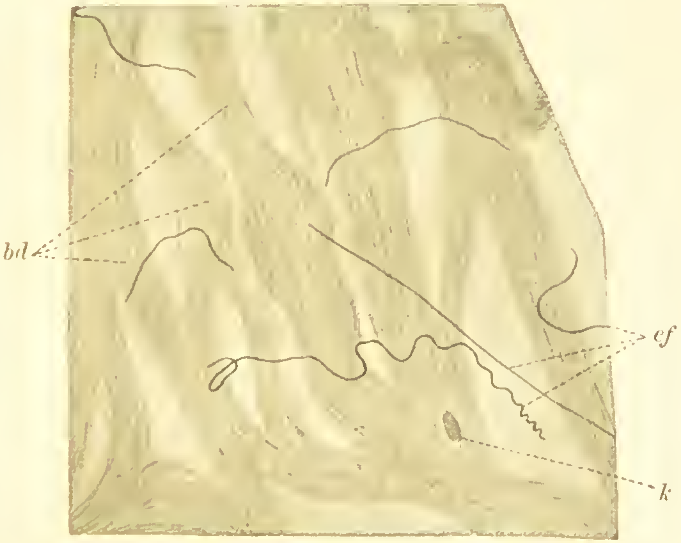

Fig. 5.—Loose intermuscular connective tissue of man. × 140. The figure shows the bundles of connective-tissue fibers, between which are elastic fibers and a connective-tissue cell. *bd*, Connective-tissue bundle; *ef*, elastic fibers; *k*, nucleus of connective-tissue cell.

the connective-tissue bundles by their different refraction and by the different chemical reactions (see page 43).

Cells are found very sparingly in the ordinary loose connective tissue of the human body, giving place almost entirely to the fibrous elements. They are generally of flattened form and lie on the connective-tissue bundles or surround them like a ring. They almost always lie at considerable distances from each other and constitute the so-called fixed connective-tissue cells. Besides these, the following occur as cellular elements of loose connective tissue: (1) *Leukocytes* (see page 57), which are found here as in nearly all tissues of the human body, even in the epithelium; (2) *plasma-cells* and *mast-cells*, large connective-tissue cells, which are rich in protoplasm (see page 41). Their number is very variable; sometimes they are found abundantly and again only singly or not at all.

Concerning the ground substance of loose connective tissue we possess very little definite information; it is probably of a nearly fluid consistency.

The loose connective tissue is distributed over nearly the entire body, but it is rarely found alone, being generally associated with adipose tissue, as intermuscular, subcutaneous, submucous, and adventitious connective tissue. The *formed connective tissue* is distinguished from the loose especially by the fact that in the latter the connective-tissue bundles have no regular arrangement, while in the former they are parallel or are arranged in a network. The ground substance is present only in small amount; in tendon it is present mostly as cement substance. Relatively few elastic fibers are present in tendon; however, in the dense connective tissue of the cutis, elastic fibers are abundant. The cells of formed connective tissue are generally more abundant than in loose connective tissue and are more regularly arranged, as is seen especially in tendon. Between the formed and loose or areolar connective tissue there are many transition forms in the human body. Areolar connective tissue also occurs in the form of supporting tissue for the formed connective tissues, as for instance in tendons (see page 93).

The dense or formed connective tissue is found with parallel arrangement of its fibers in the tendons, fasciæ, and fibrous membranes, and in the cornea; with reticular arrangement of fibers and with more irregular course, frequently passing over into other connective tissues without any sharp boundary lines, in the peritoneum and great omentum, in the cutis, and in the basal layer of mucous membranes.

Elastic tissue, which is often not clearly separated from fibrous connective tissue or passes over into the latter without distinct demarcation, is characterized by the presence of numerous, generally large, elastic fibers of almost parallel arrangement. Typical elastic tissue is found in the ligamentum nuchæ, especially of large quadrupeds. In the ligamentum nuchæ are found large elastic fibers, which frequently anastomose in a framework of loose connective tissue.

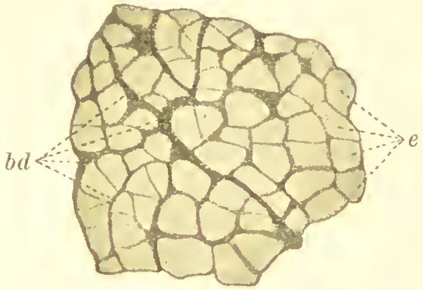

Fig. 6.—Portion of a cross-section of the ligamentum nuchæ of the ox. × 420. *bd*, Loose connective tissue; *e*, elastic fibers.

Nearly pure elastic tissue is further found in the mucous membranes of the respiratory tract, especially of the larynx (membrana elastica), of the trachea, of the bronchi, and of the lungs (alveolar wall); also in the vascular system, in which elastic membranes occur in addition to the elastic fibers (see page 43).

Gelatinous connective tissue, the first subdivision of the connective tissues characterized by their ground substance, cannot be said to occur, as such, in the adult;

Fig. 7.—Gelatinous connective tissue from a cross-section of the umbilical cord of the new-born. × 280. *F*, Fibers; *Z*, cells with fine granules of fat in the protoplasm.

Fig. 8.—Portion of a cross-section of a human costal cartilage. × 250. The figure shows the typical picture of a hyaline cartilage with cartilage capsules, which contain two or more cells. In the protoplasm, and also in the nuclei of the cells, fat droplets are found. *f*, Fat droplets; *K*, nuclei of cartilage cells; *kk*, cartilage capsules; *Z*, cartilage cells.

however, several of the very loose connective tissues, with a scarcity of fibers, possess a ground substance which is gelatinous or semi-fluid, as for instance the tissue surrounding the membranous semicircular canals, and such connective tissues closely resemble gelatinous connective tissue. In the new-born, typical gelatinous tissue is found in the *umbilical cord*. The structure of this varies but slightly from embryonal connective tissue, and of all the varieties of connective tissue it is the one which most closely resembles mesenchymal tissue. The ground substance is gelatinous, the tissue is rich in cells, the processes of which distinctly anastomose. In mesenchymal or embryonic connective tissue there are, when first developed, no fibers; in gelatinous connective tissue they are present in moderate number and, even when most fully developed, form an inconspicuous portion of the tissue. Very frequently gelatinous connective tissue occurs in pathologic formations.

Cartilaginous tissue is readily distinguished from all other kinds of connective tissue by its ground substance, which, though elastic, is hard and, when uncalcified, can be cut and yields *chondrin* on boiling.[1] Of the different kinds of cartilage which occur in the animal kingdom, only three are found in the human body: (1) Hyaline cartilage; (2) elastic cartilage or reticular cartilage; (3) connective-tissue cartilage or white fibro-cartilage.

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[1] In a wider sense certain tissues are characterized as cartilage which have a cartilaginous consistency, but which consist of pure connective tissue (tarsal cartilage, etc.), or even the embryonal chorda dorsalis, which genetically is quite a different structure.

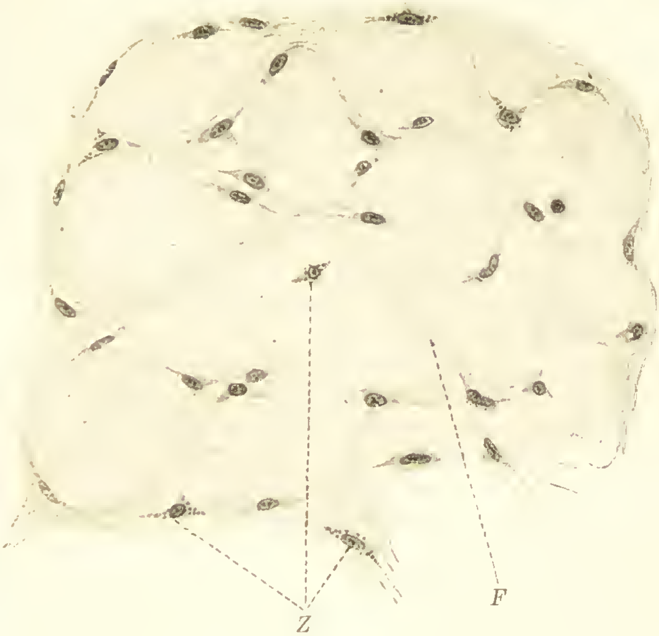

Fig. 7.

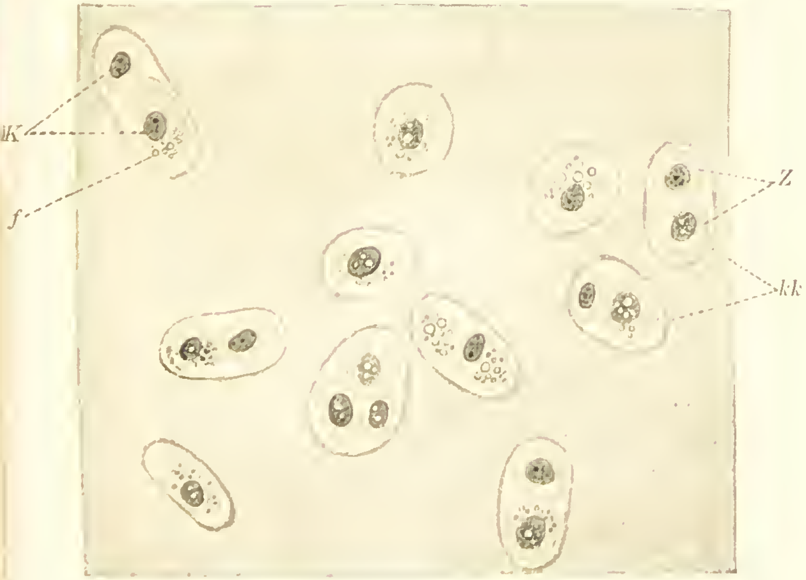

Fig. 8.

Hyaline cartilage is opaque and bluish-white in color. Its ground substance is homogeneous, transparent or translucent, and yields chondrin; in the ground substance there are found, especially as the age of the individual advances, peculiar fibrillar structures, which, like the ground substance, yield chondrin on boiling. Calcification of the ground substance occurs in many cartilages as age advances and also during endochondral bone development. The *cartilage cells* are found in spaces in the ground substance, the *cartilage spaces,* occurring at variable distances from each other.

In many hyaline cartilages each cartilage space is surrounded by a narrow zone of ground substance which is characterized by stronger refraction of the light; this is known as the *capsule* of the cartilage cell. In the cartilage spaces are found the cartilage cells, which are round or oval in shape and without processes.[1] They occur in groups of one, two, or even occasionally more cells.

Young or embryonic cartilage is poor in ground substance and rich in cells. The cells divide mitotically and a new capsule forms about each daughter cell, forming a bridge of hyaline ground substance, so that each new cell finally lies in a new space. In mature cartilage this does not appear to happen in all cases; for this reason, in most hyaline cartilage, spaces are found which contain more than one cell. It is very common to find two neighboring cells which are flattened by contact; occasionally, especially in costal cartilage, long cartilage spaces occur containing rows of cartilage cells. We possess no evidence that cartilage cells divide amitotically. Hyaline cartilage is very widely distributed in the human body as the cartilages of the joints, the costal cartilages, the nasal cartilage, certain of the cartilages of the larynx, cartilage of the trachea and of the larger bronchi.

Elastic cartilage is characterized by the presence of elastic

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[1] In lower animals there are varieties of cartilage in which the cells are connected by processes. (See Nutrition of Cartilage.)

Fig. 9.—Portion of a cross-section of the elastic cartilage of the external ear of man. × 280. The figure shows the typical picture of elastic cartilage. *cf*, Elastic fibers; *K*, nuclei of cartilage cells; *kk*, capsules of cartilage cells.

Fig. 10.—Portion of a section of the intervertebral disc from man. × 260. *K*, Nucleus of cartilage cell; *kk*, cartilage capsules; kk_1, cartilage capsules with calcification granules; *Z*, cartilage cell.

fibers in the ground substance. In certain places the hyaline cartilage passes over gradually and without any definite line of demarcation into elastic cartilage. The latter, however, also occurs independently. Elastic fibers, varying in size, form dense networks, especially about the cartilage spaces. Where the elastic cartilage occurs without transition into hyaline cartilage, as in the cartilage of the pinna of the ear and of the epiglottis, the network of elastic fibers is dense and nearly fills the entire ground substance throughout the cartilage. Where there is a gradual transition from one kind of cartilage to the other, as at the end of the vocal processes of the arytenoid cartilages and generally in the cartilages of the smaller bronchi, a few fine single elastic fibers are found in the hyaline ground substance, which gradually become more abundant and denser, and finally, forming networks, acquire the same character as in pure elastic cartilage.

White *fibro-cartilage* is characterized by the fact that bundles of connective-tissue fibers are found in a very small amount of ground substance, between which cartilage cells lie in distinct cartilage spaces. The cartilaginous nature of this form of cartilage is doubtful, especially as it does not yield chondrin on boiling. The statements regarding the occurrence of this form of cartilage, in places where simple fibrous tissue seems to occur at times, are very variable. In any case the occurrence of white fibro-cartilage in man is limited to the fibro-cartilaginous intervertebral discs and certain interarticular discs and ligaments.

Cartilage and dentine are probably the only kinds of connective tissue which contain no blood- and lymph-ves-

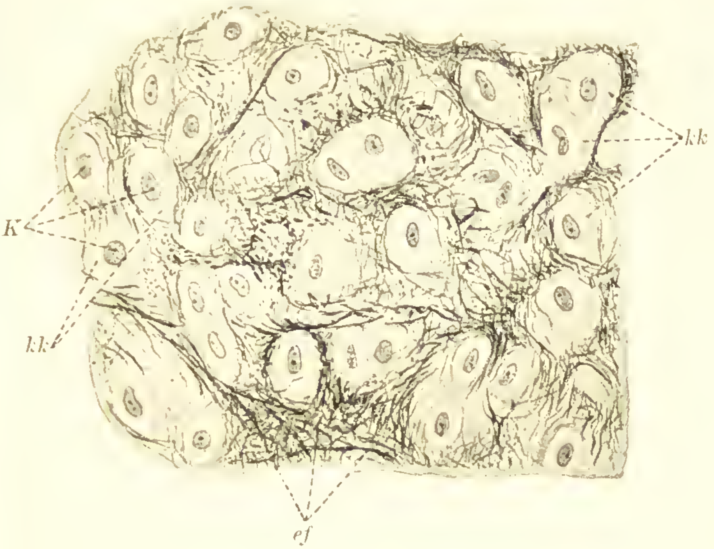

Fig. 9.

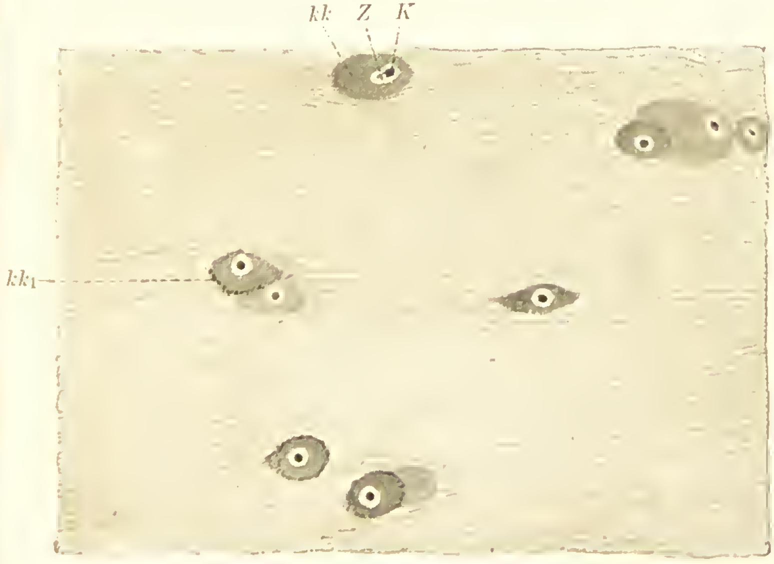

Fig. 10.

sels and probably no nerves. Whether the hyaline ground substance contains fine canals for carrying nutrition is doubtful. In any case the nutrition of cartilage, which is provided for from the firm connective-tissue capsule enveloping the cartilage, the perichondrium, seems imperfect, so that the larger cartilages almost invariably, by the entrance of blood-vessels from the perichondrium, begin to change into bone tissue (large cartilages of the larynx).

The **structure of bone and dentine** will be discussed when considering these tissues. We shall now consider the third group of connective tissues, characterized by cellular elements.

Adipose tissue in the fully developed condition consists of collections of *fat-cells*. These are bound together by bundles of loose areolar connective tissue to form fat-lobules.

The fully developed fat-cell is spherical, has a distinct cell membrane, and consists essentially of a large spherical fat-drop, which crowds remains of protoplasm and nucleus so that they represent only a narrow border within the cell membrane. The flattened nucleus of the fat-cell contains usually a refractive globule, either a vacuole or fat droplet. In the dead (cold) fat-cell, fatty acid crystals often crystallize out in the form of needles.

Adipose tissue is very rich in blood-vessels, which, in the form of capillaries, form a dense network between the fat-cells. Adipose tissue is almost always found in company with loose connective tissue, so that sometimes one and sometimes the other predominates. It occurs as subcutaneous tissue mixed with loose connective tissue, and also as interstitial tissue almost all over the body.

Adipose tissue may to a certain extent be formed from ordinary connective tissue, since connective-tissue cells form or take up small fat-drops, which become larger and finally fill the whole cell in the typical way. Fat-cells thus developed are not grouped into lobules of fat. On the other hand, adipose tissue may become atrophic and thus resemble fibrous connective tissue, in that the fat-drops become smaller and finally entirely disappear. Such atrophic adipose tissue is, however, not identical with fibrous connective tissue.

Pigmented connective tissue (see Plate 6, Fig. 1) is found very sparingly in the human body, while in the lower animals it has a wide distribution, and in certain forms all the fibrous connective tissue is pigmented. In man it is constantly and well developed only in the choroid and iris. The characteristic feature of this connective tissue is that the relatively abundant connective-tissue cells contain fine differently colored pigment granules (yellow, brown, or black), which nearly fill the body of the cell; at the same time the tissue contains few fibers. The presence of pigment in connective tissue is always associated with the protoplasm of the cells. Even when pigment occurs in small amounts, in fibrous connective tissue, as occasionally in the skin and in other places, it is always carried by the cells. The pigmented connective tissue in man is not sharply separated from ordinary con-

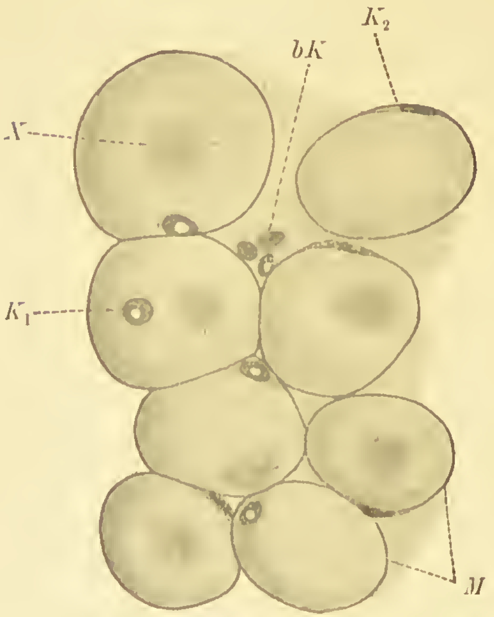

Fig. 11.—Adipose tissue from the orbital cavity of man. × 280. The figure shows fat-cells with fatty acid needles. The nuclei contain vacuoles. *bK*, Nucleus of connective-tissue cell; K_1, nucleus of fat-cell seen in surface view; K_2, nucleus of fat-cell seen from the side; *M*, membrane of fat-cell; *X*, crystals.

nective tissue. It is relatively rich in cells; it generally appears as areolar tissue, similar to the ordinary loose connective tissue, but it is much poorer in fibers, which rarely form large bundles.

Lymphoid or **adenoid tissue** is a form of connective tissue which is very widely distributed in the human body. It is found in a compact form in all lymph-glands, in the thymus gland, spleen, and all the smaller lymphatic structures of the digestive tract and of other mucous membranes; in the diffuse form it occurs in the red bone-marrow and many mucous membranes, as for instance in the uterus and the intestine. The lymphoid tissue may be said to consist of two types of connective tissue, which together form such organs as the lymph-glands, thymus, and spleen; one is a fine connective-tissue framework, which is partly fibrous and partly cellular, the *reticular* tissue, and the other a mass of round cells filling the interstices of the reticulum. The elements of the latter belong to the category of the *lymphocytes* and *leukocytes* or colorless blood-cells (see page 57). They are round or oval elements, with large round nuclei, and enter the circulation as lymphocytes or mononuclear leukocytes. In the bone-marrow (see page 61) and in the spleen other forms of cells are found. In the lower vertebrates the reticular connective tissue is formed of anastomosing stellate cells. In the higher vertebrates and especially in the larger mammalia, the reticulum consists for the greater part, and in certain regions perhaps even exclusively, of finer and coarser branching and anastomosing connective-tissue trabeculae, composed of reticular and white fibrous tissue fibrils on which lie flattened cells.

With the exception of cartilage, dentine, and the connective tissue of the cornea, all forms of connective tissue contain blood-vessels, though generally in small numbers. The cornea contains nerves; only cartilage, bone, and dentine seem to be devoid of nerves.

Lymph-vessels, as such, are rarely found in connective tissue, but the cell spaces and canaliculi are probably to be regarded as the radicles of the lymph vascular system. These are to be observed most distinctly in bone, lying between the cells and the walls of the Haversian canals and in the cornea, where they also occur as pericellular spaces, between the cells and the ground substance. In many kinds of connective tissue, the tissue fluid seems to circulate in the ground substance, as in cartilage.

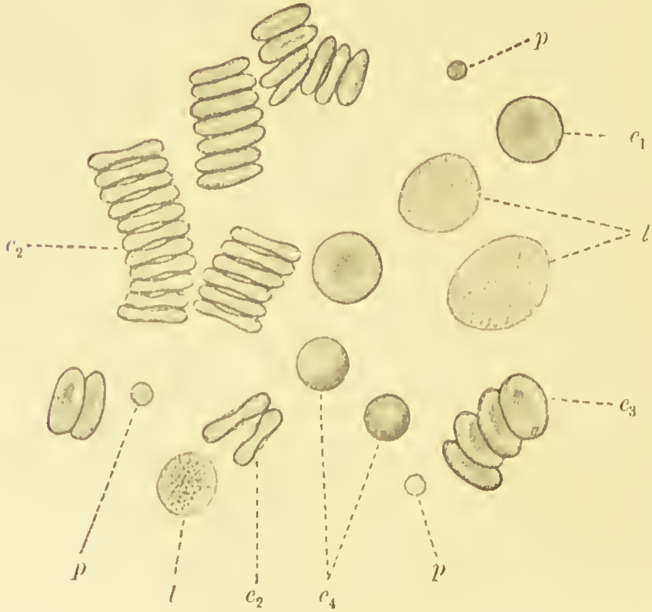

Fig. 12.—Fresh blood without the addition of fluid. × 850. The figure shows red and white blood-cells and blood platelets. c_1, Red blood-cells seen on the flat surface; c_2, red blood-cells seen on edge (rouleaux); c_3, red blood-cells seen partly from the side; c_4, spherical red blood-cells; *l*, leukocytes; *p*, blood platelets.

Blood.—Although in the adult body the blood, on account of the lack of any regular arrangement of its elements, does not appear as a typical tissue and is not so regarded by the majority of authors, yet histogenetically it is scarcely to be separated from the connective tissues, and we are therefore warranted in considering it a tissue with a fluid intercellular substance.

The blood is composed of a blood fluid, the *blood plasma*, and of the formed elements, the *blood-corpuscles* or blood-cells and the *blood platelets*. The blood plasma is regarded as the intercellular substance, since it originates embryologically as an intercellular substance. As the blood plasma is homogeneous, it cannot be analyzed *microscopically*.

Blood-corpuscles are divided into two main, sharply defined groups—the colored blood-corpuscles, or erythrocytes, and the colorless or white corpuscles, the lymphocytes and leukocytes. The **colored** or **red corpuscles** appear yellow under the microscope; it is only in thicker layers that they appear red. In the adult condition at least they have no nuclei and are therefore *non-nucleated* cells. The human red blood-cells measure on an average 7.5 μ in the long diameter and 1.6 μ in the short diameter. In man one cubic millimeter contains on an average 5,000,000 red blood-cells. The views concerning the structure of the red blood-cell are still somewhat at variance, but it is very probable that it possesses a very thin cell membrane; within this is found a fine protoplasmic framework known as the stroma, the meshes of which are filled with the coloring matter of the blood, the hemoglobin.

Besides the disc-shaped cells, spherical red blood-cells are occasionally found, and very rarely we may find in the circulating blood nucleated immature red blood-corpuscles (generally only after severe loss of blood).

The ordinary disc-shaped red blood-corpuscles of man have a tendency, when they are present in the preparation in large numbers and in a thick layer, to lie together and form so-called *rouleaux*. They are very sensitive to reagents and especially to evaporation, which produces a concentration of the salt solution of the blood, so that water is withdrawn from the blood-corpuscles. As a result, the membrane shrinks and the so-called *crenated form* of blood-corpuscles develops. Water, especially distilled water, ether, chloroform, and many other reagents remove the hemoglobin from the blood-cells, which are

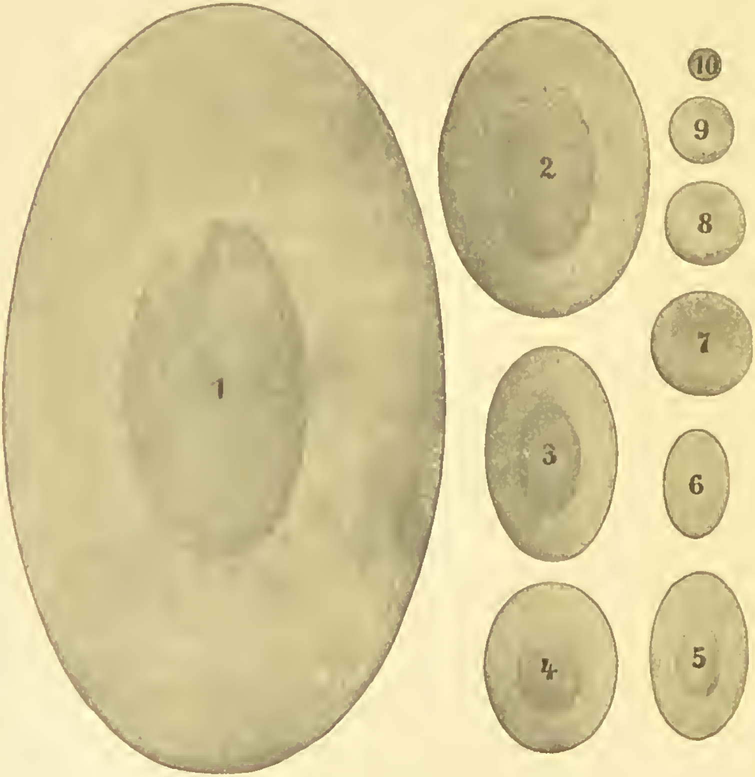

Fig. 13.—Photographs of the Welcker blood-corpuscle models, representing the corpuscles 1500 : 1. The figures after the name give the size of the red blood-corpuscles: *1*, Proteus, 58 : 35 μ; *2*, frog, 22.3 : 15.7 μ; *3*, lizard, 15.79 : 9.9 μ; *4*, tench, 12.8 : 10.2 μ; *5*, chaffinch, 12.4 : 7.5 μ; *6*, llama, 8 : 4 μ; *7*, man, 7.2 : 7.8 μ; *8*, dormouse, 6.2 μ; *9*, goat, 5.4 μ; *10*, muskox, 2.5 μ.

then scarcely visible under the microscope, producing the structures known as blood shadows.

Only the blood-cells of mammalia are biconcave circular discs with rounded edges and non-nucleated. The tylopods, camel, llama, and others, whose red blood-corpuscles are elliptic, but non-nucleated, are the only exceptions to this rule. The red blood-cells of all other vertebrates are nucleated biconvex discs of elliptic form, the convexity being caused by the oval nucleus.

The amphibia have the largest blood-corpuscles, especially the tailed amphibia with persistent gills. The smallest red blood-corpuscles are found in certain mammalia (see Fig. 13).

It is forensically important to know the form and size of the blood-corpuscles. In size, the human blood-corpuscles stand nearest to those of many domestic animals. It is therefore impossible, from the size of the corpuscles, to reach a decision as to whether human blood or for instance dog's blood is before us.

The *hemoglobin* from the blood-corpuscles crystallizes in forms which are different in different animals (in man, in rhombic prisms). It is possible to obtain hemoglobin crystals only from fresh blood or from fresh clots, and even this is often accomplished with difficulty. Occasionally, but generally only pathologically, *hematoidin crystals* occur in old blood exudates; these represent a transformation product of the hemoglobin.

Even from very old traces of the blood of every species of animal whose blood-cells contain hemoglobin, *crystals of chlorid of hematin* (*hemin*) can be obtained, which appear in the form of long, needle-like, rhombic crystals of dark brown color.

The discovery of hemin crystals shows only that blood is before us and not that the blood is human. Frog's blood and fish's blood, for instance, give the same hemin crystals as human blood.

The **colorless** (white) **blood-corpuscles** form a large group of cells of mesenchymal origin, which occur, not only in the blood, but also in the lymph, as lymphocytes form the chief constituent of adenoid connective tissue (see page 53); they are also found scattered in almost every variety of connective tissue and even occur between the cells of epithelial tissues. The number of the white blood-cells varies in circulating blood within certain limits, their proportion to the erythrocytes being as 1 : 300 : 500.

Several varieties of white blood-cells are recognized, the classification being based on the form, size, and structure of the nucleus, on the relative amount and the structure of the protoplasm, and on the origin. The following varieties are distinguished: (1) Small and large lymphocytes; (2) mononuclear leukocytes; (3) transitional leukocytes; (4) polymorphonuclear leukocytes and polynuclear leukocytes.

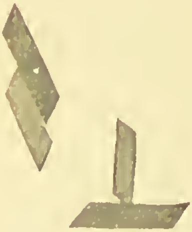

Fig. 14.—Representation of hemin crystals from dried human blood. × 700.

The lymphocytes vary in size from 5 μ to 7.5 μ and possess a relatively large nucleus, which stains deeply and is surrounded by a narrow zone of protoplasm. They form about 20 per cent. of the white blood-cells and are developed in adenoid tissues.

The mononuclear leukocytes vary in size from 7 μ to 10 μ and possess a round or oval nucleus, relatively smaller than that of the lymphocytes and which, in most dyes, is not colored very deeply. They constitute 2 to 4 per cent. of the white blood-cells. The mononuclear leukocytes very probably originate in the spleen and bone-marrow and develop into the transitional forms and these in turn into the polymorphonuclear forms. The transitional leukocytes constitute from 2 to 4 per cent. of the white blood-cells and possess a nucleus of more or less pronounced horseshoe shape, of a size and structure similar to that seen in the mononuclear variety. The polymorphonuclear leukocytes form from 60 to 70 per cent. of the white blood-cells and possess variously lobulated nuclei, the several nuclear masses being united by delicate threads of protoplasm. A polymorphonuclear leukocyte develops into the polynuclear form when the delicate bridges of nuclear substance uniting the several lobules of the nucleus of the former break through. In the leukocytes with polymorphous nuclei there is found in the center of the lobular nuclear mass a centrosome which is often difficult to demonstrate; in the resting stage of the cell, fine rays radiate from this. By means of special staining methods, the presence of granules can be shown in the protoplasm of the transitional, polymorphonuclear, and polynuclear leukocytes of the blood and lymph and of certain blood-forming organs; in the latter, mononuclear cells with round or oval nuclei, possessing granules in their protoplasm, are found. These granules show specific reaction toward certain anilin stains or combinations of such stains, and according to their staining power they are divided into the following sub-classes: (1) Those which stain with the acid anilin dyes and especially with eosin are known as oxyphile or eosinophile granules; (2) granules which show an affinity for basic stains are known as basophile granules; (3) granules which stain in certain combinations of acid and basic anilin stains, the so-called neutral staining mixtures, are known as neutrophile granules; (4) granules which stain in both basic and acid anilin stains are designated amphophile granules.

The leukocytes with eosinophile granules form 1 to 4 per cent. of the circulating white blood-cells. The granules are coarse and can be recognized with moderately high magnification even in unstained cells. They stain a bright red in eosin and occur in normal blood in cells with horseshoe-shaped or lobulated nuclei. In bone-marrow they are also found in mononuclear cells with round or oval nuclei. They are found in the connective tissue of the intestine, and in certain pathologic states are found in greatly increased numbers in connective tissue.

The basophile granules occur in two sizes: first, as large granules very little smaller than the oxyphile; these are found in the so-called mast-cells (see page 41) and rarely occur in the normal circulating blood, but are found

PLATE 5.—BLOOD.

FIGS. 1-21.—**Blood-corpuscles from Human Blood.** × 700. The figure shows the different forms of erythrocytes, lymphocytes, and leukocytes.

Technic: Dry preparation. Ether-alcohol. Hematoxylin-eosin. In 1, 3, and 4, Ehrlich's triacid solution.

Figs. 6-12.—Erythrocytes.

Fig. 9.—Nucleated red blood-corpuscles.

Figs. 1-5 and 13-21.—White blood-cells.

Fig. 1.—Small lymphocyte, having a small amount of protoplasm and large nucleus.

Figs. 2 and 3.—Polynuclear leukocytes with neutrophile granulation.

Figs. 4, 5, 14, 16, and 18.—Ordinary polynuclear leukocytes.

Figs. 15, 19, and 21.—Leukocytes of different sizes, having acidophile (eosinophile) granulation.

Figs. 13 and 20.—Large lymphocytes.

Fig. 17.—Mononuclear leukocyte.

FIGS. 22-31.—**Elements of the Bone-marrow of a Mouse.** × 700.

The preparation was taken from the femur of a full-grown mouse. The figure shows one of the large giant-cells of the bone-marrow, ordinary and nucleated red blood-corpuscles, different kinds of marrow-cells including leukocytes, among them eosinophile cells and mitotically dividing cells.

Technic as above.

Fig. 22.—Polynuclear giant-cell.

Figs. 23-28.—Marrow-cells.

Fig. 23.—Marrow-cell with annular nucleus (goes through the nuclear stage of 25 into that of 24—that is, into the ordinary polymorphonuclear cell).

Figs. 25 and 26.—Acidophile cells.

Figs. 27 and 28.—Mitoses.

Fig. 29.—Ordinary erythrocyte.

Figs. 30 and 31.—Nucleated erythrocytes.

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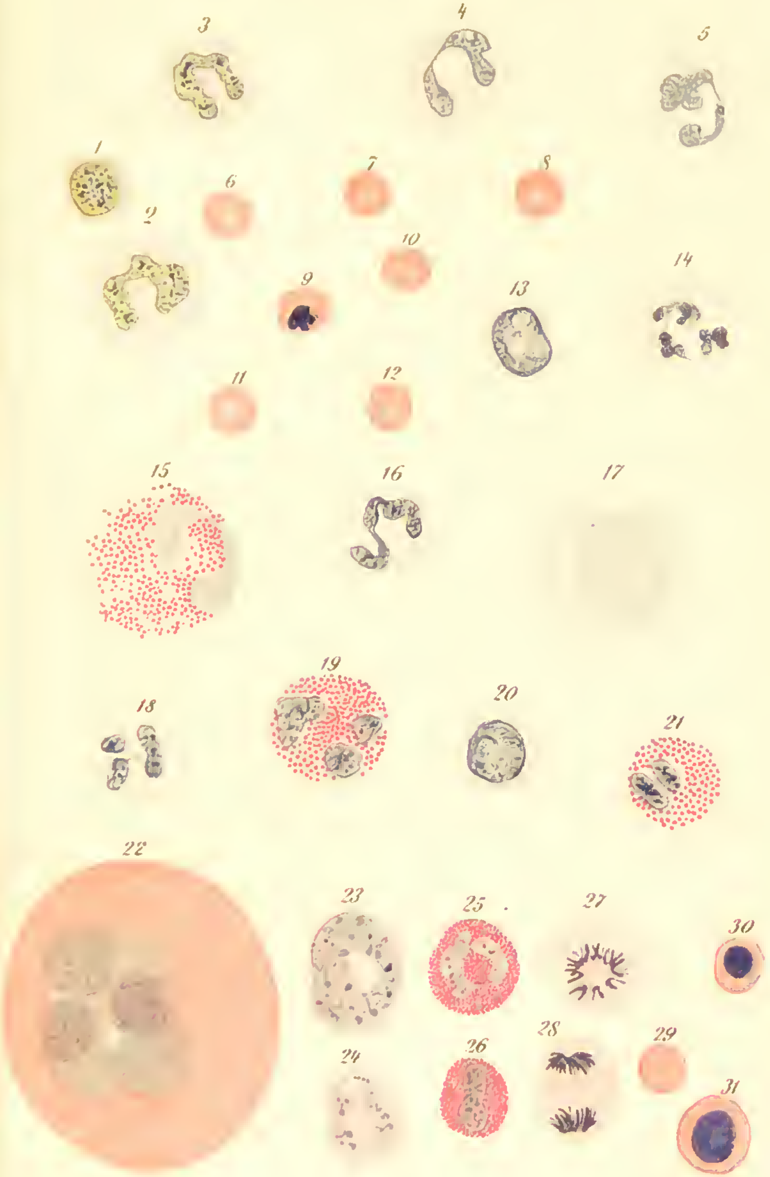
in certain pathologic conditions; second, as very fine granules which are visible only under high magnification; these are seen in the leukocytes of the circulating blood, such cells forming a small percentage of the white blood-cells.

The leukocytes with neutrophile granules form 65 to 68 per cent. of the polymorphonuclear forms found in the circulating blood. They are very fine granules, not readily seen unless oil-immersion lenses are used. Neutrophile granules further occur in certain mononuclear cells

Tab. 5.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of the bone-marrow (myelocytes); in certain pathologic conditions such cells are seen in circulating blood.

Amphophile granules occur in the leukocytes of many mammals, both in the circulating blood and in the bone-marrow.

The **blood platelets** are colorless discs of round or oval form, measuring 2 μ to 3 μ, and are in proportion to the red blood-cells as 1 : 25 or as 1 : 40. They are constant constituents of the human blood. Their structure and development have not yet been fully determined. Certain investigators regard them as nuclear fragments of either the red blood-cells or of the leukocytes. According to more recent investigations, the blood platelets or the thrombocytes, as they are known on account of their relation to the coagulation of the blood, are small nucleated cells, which are destroyed in the process of coagulation. It has been shown that they possess ameboid movement.

Red bone-marrow consists of a delicate reticulum of fibrous and reticular connective tissue, in the meshes of which are found numerous cellular elements. The cellular elements of the bone-marrow are: (1) Leukocytes and lymphocytes, as found in circulating blood. (2) Myelocytes. These are mononuclear cells, slightly larger than the leukocytes, with round or oval nuclei, which stain faintly, and a protoplasm containing neutrophile granules, now and then vacuoles and pigment granules. These cells are found in circulating blood in certain pathologic states. (3) Numerous cells with eosinophile granules in the protoplasm, the nuclei of which may be either round or oval, horseshoe-shaped or polymorphous, are found. (4) We further meet with cells with vacuolated or annular nuclei. These cells probably develop into the leukocytes with polymorphous nuclei. (5) Between the ordinary marrow-cells are scattered *giant-cells,* large, spherical cells, rich in protoplasm, with several and often many nuclei. The nuclei often lie in a group or mass, and occasionally in the form of a crescent. The diameter of these cells often reaches 100 μ. (6) In addition to the fully developed red blood-cells, we also find in the bone-marrow *nucleated red blood-cells* still in the process of formation. The bone-marrow is the seat of *blood formation*. In its tissue, new red blood-cells are formed, the developmental stage of which, here as well as in embryonal blood development, is nucleated. They reach the veins of the bone-marrow after they have lost their nuclei. There is as yet controversy as to the manner in which the nucleus is lost. Certain investigators believe that the nucleus is extruded, while others state that it is absorbed or lost by chromatolysis.

MUSCLE TISSUE.

Both as to structure and function, *muscular tissue* is divided into two great subdivisions: (1) Transversely striated or voluntary muscle (cardiac muscle is striated, but involuntary); (2) non-striated, smooth, or involuntary.

Involuntary muscle consists of long, spindle-shaped mononuclear cells, exhibiting the character of ordinary cells. They vary in size, and especially in length, measuring from 50 μ to 150 μ in their long diameter and from 5 μ to 8 μ in their thickest portions. Very large smooth muscle-fibers are found in the musculature of the seminal ducts, and still larger fibers in the musculature of the pregnant uterus, where they may attain a length of 500 μ.

The typical smooth muscle-cell or fiber is fusiform. In the middle of the thickest portion is found an elongated nucleus, which has the form of a short rod with rounded corners. The two ends of the smooth muscle-fiber are sharply pointed. The protoplasm of the smooth muscle-fiber stains quite intensely with acid anilin dyes, as eosin, etc.; as a result, smooth muscle can often be readily distinguished from the surrounding connective tissue. In the protoplasm of the larger cells a distinct longitudinal striation may be observed, due to the presence of fibrils which run parallel or nearly parallel to the long axis of the cell; these are more clearly made out in cross-sections of the cells, in which they appear as minute granules.

The involuntary muscle-cells are inclosed within delicate fenestrated connective-tissue membranes, so disposed that two contiguous involuntary muscle-cells are separated by a single membrane. The intercellular bridges described by certain observers are due to faulty technic and are to be regarded as artefacts.

Non-striated muscle-fibers may occur in relatively large, compact masses, with regular arrangement of the cellular elements, and then form the so-called *involuntary musculature.* The musculature of almost all the abdominal organs is of this variety, as in the stomach, intestine, bladder, uterus, etc. They also occur, however, scattered in small bundles and even in single fibers, as in the mucous membrane of the stomach and in the villi of the intestine, and in certain regions form typical networks, as in the bladder. (See Plate 58, Fig. 2.)

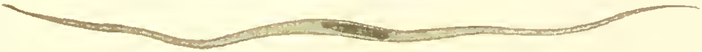


Fig. 15.—Isolated involuntary muscle-cell from the intestine of a frog, in the middle of which the nucleus is seen. × 320.

Where involuntary muscle occurs in larger amounts, bundles or fasciculi of the tissue are surrounded by connective-tissue sheaths which penetrate between the single groups of fibers. This connective tissue also carries the abundant blood- and lymph-vessels. Blood capillaries are found between the single muscle-fibers. Smooth musculature is supplied exclusively by the neuraxes of sympathetic neurones.

Smooth musculature is very widely distributed in the human body. It is found in the entire digestive canal from the middle of the esophagus to the anus, in the gall-bladder and the larger bile-ducts, in the excretory ducts of many glands, in the urinary passages, in the efferent passages from the male and female reproductive organs, in the blood and lymph vascular system, in the eye, in the respiratory passages, and in the skin.

The elements of **transversely striated, voluntary muscle,** in contrast to those of non-striated muscle, are not simple cells, but cell syncitia or plasmodia.

Histogenetically, each striated muscle-cell or fiber arises from a single cell (one of the cellular elements of the myotomes of the primitive vertebræ). A proliferation of the nucleus takes place by mitotic division, without subsequent division of the protoplasm. At the same time a very considerable elongation of the cell takes place with development of contractile fibrillæ.

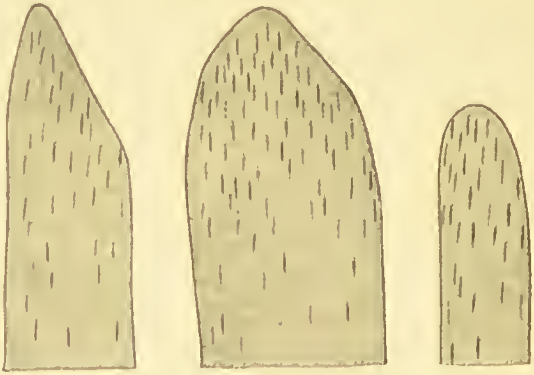


Fig. 16.—Ends of three isolated striated muscle-fibers of the frog. The figure at the left shows an intermuscular and at the right a tendinous termination. × 100.

The cross-striated muscular fibers are usually of long cylindric shape, with rounded or beveled ends. They are often of considerable length, measuring 12 cm. and more in long parallel-fibered muscles. The thickness of the muscle-fiber varies between about 10 μ and 100 μ. Each muscle-fiber has two free ends; these may either, as in short muscles, run from tendon to tendon, or the fiber may begin with the one free end in tendon and end free in muscle; or, as is the case in very long muscles, certain of the muscle-fibers do not reach the tendon, but have two intermuscular ends. The *tendon ends* of the muscle-fibers are generally rounded and characterized by collections of nuclei (see Fig. 16). The *intermuscular ends* are beveled; the beveled ends of adjoining muscle-fibers are said to be united by cement substance.

Each striated muscle-fiber is surrounded by a dense homogeneous membrane, the sarcolemma, which is easily isolated; this represents the cell membrane of transversely striated muscle-fibers. Within the sarcolemma is contained the muscle substance, in which are recognized the contractile ultimate fibrils, the interfibrillar substance, the sarcoplasm, and the nuclei.

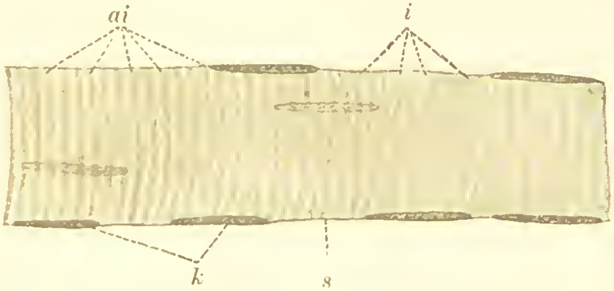


Fig. 17.—Longitudinal section of a small muscle-fiber from the human eye muscle. × 450. *ai*, Anisotropic substance; *i*, isotropic substance; *k*, nuclei; *s*, sarcolemma.

Functionally, the most important constituents are the *cross-striated* contractile *fibrillæ*, which give the characteristic cross-striated appearance to the entire muscle-fiber. Frequently also the fibrillæ give to the muscle-fiber a distinct longitudinal striation, especially *when the interfibrillar substance is relatively abundant*, as in lower animals.

The fibrillæ are fine fibrillar structures, arranged in the long axis of the fiber and taking up the entire length of the fiber; under the microscope they show alternate dark and light segments. The segments which appear dark consist of doubly refracting, anisotropic substance; the segments which appear light, of singly refracting, isotropic substance. More careful investigation shows that in the middle of the isotropic substance a fine anisotropic intermediate disc is found, and similarly in the middle of each anisotropic segment there occurs an isotropic median disc. The fibrillæ are firmly united by an interfibrillar substance, and can be recognized only after the use of special methods.

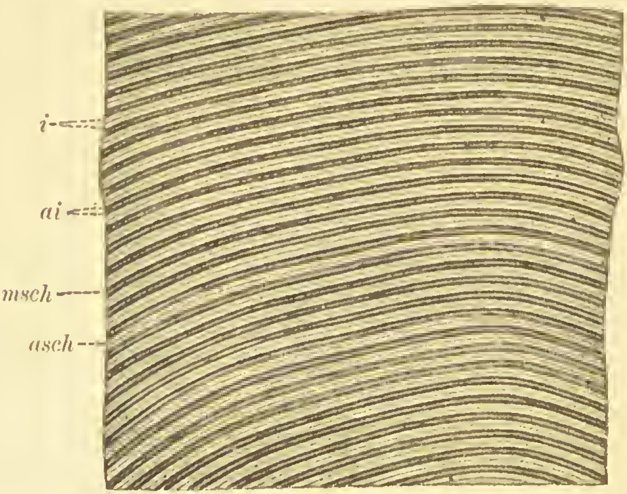


Fig. 18.—Portion of a fresh, isolated, transversely striated muscle-fiber of man. × 550. The figure shows the cross-striation very distinctly. We recognize in the middle of the anisotropic median disc the isotropic median disc, and in the middle of the isotropic substance, the anisotropic intermediate disc. *ai*, Anisotropic substance; *i*, isotropic substance; *msch*, isotropic median disc; *asch*, anisotropic intermediate disc.

The fibrillæ are not evenly and regularly arranged throughout the muscle-fiber, but are united into groups, the so-called *muscle columns*. The several muscle columns are separated by *sarcoplasm*, the remains of the original cell protoplasm, not changed into fibrillar substance. The relative amount of sarcoplasm varies in different muscle-fibers, so that the boundaries of the muscle columns are sometimes more and sometimes less distinct. Occasionally, and especially in the vicinity of the nuclei, the sarcoplasm contains granules, the so-called interstitial granules; these are mostly fat and pigment granules.

Fig. 19.—Portion of a cross-striated muscle-fiber of the larva of a salamander; this is breaking up into fibrillæ. × 700.

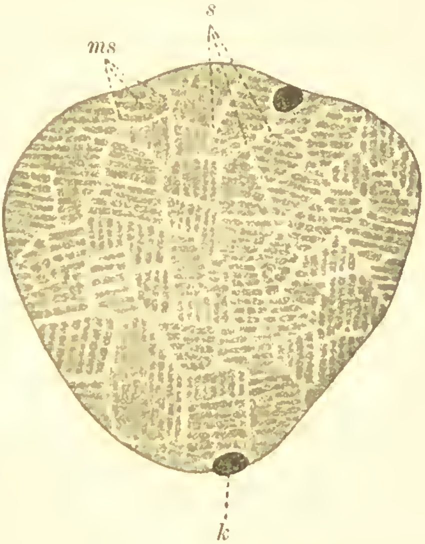


Fig. 20.—Cross-section of a human muscle-fiber, rich in sarcoplasm. × 780. The figure shows the arrangement of the muscle columns. *k*, Nucleus of muscle-fiber; *ms*, muscle column; *s*, sarcoplasm.

The disposition of the sarcoplasm and the arrangement of the muscle columns are best recognized in the cross-section of the muscle, in which we may recognize a division into several irregularly outlined fields of different sizes, known as *Cohnheim's areas.*

According to the amount of sarcoplasm, we distinguish two kinds of muscle-fibers—so-called dark or red fibers, rich in sarcoplasm, and light or white fibers, which are poor in sarcoplasm. In general, the red fibers are found in varying but small numbers scattered between the white fibers. In certain animals, however, for instance in the rabbit, certain muscles, as for example the semitendinosus, consist entirely of the red variety of fibers, while other muscles, as for example the semimembranosus, consist entirely of the white variety of fibers. In many muscle-fibers of the white variety the amount of sarcoplasm is so small that it is difficult to distinguish between the several muscle columns.

Besides the sarcoplasm found between the muscle columns, collections of sarcoplasm are found around the nuclei of the muscle-fiber. The *nuclei* of cross-striated voluntary muscle-fibers are very numerous. Long fibers have hundreds of nuclei. In the great majority of the muscle-fibers all nuclei lie at the periphery, immediately under the sarcolemma, in a small collection of sarcoplasm. They have an elongated, elliptic form.

Branched, cross-striated muscle-fibers occur in certain regions. The superficial muscle-fibers of the *tongue*, especially the ends of the fibers inserted into the mucous membrane, show this peculiarity. The branches show the same structure as the parent fiber. In the frog's tongue, branched cross-striated muscle-fibers are very abundant and complex.

Cross-striated muscle is very widely distributed; it comprises all skeletal muscles, the larger muscles of the skin, the extrinsic eye muscles, the muscles of the middle ear, portions of the musculature of the digestive tract (tongue, pharynx, part of the esophagus), the larynx, the muscles of the perineum, of the external genital organs, and the sphincter muscles of the anus.

Heart muscle occupies a special position, in that it differs histogenetically and physiologically from voluntary, cross-striated muscle, and structurally both from non-striated muscle and from voluntary, cross-striated muscle. It is cross-striated, but not subject to the will. In many respects heart muscle resembles involuntary muscle more closely; it is, like involuntary muscle, developed from the mesenchyme, and not, like striated, voluntary muscle, from the myotomes. In many lower animals, as for instance in the frog, heart-muscle fibers assume a distinct median position between smooth and striated muscle, rather more closely resembling the non-striated muscle.

Heart muscle, after fixation and hardening with the majority of the reagents in ordinary use in the laboratories, as also after treatment with macerating fluids, appears to consist of irregularly shaped oblong cells, possessing usually one, but occasionally two nuclei, situated in the center of the cells. These cells appear to be cemented end to end to form the heart-muscle fibers. The cells show irregular but short side branches, which anastomose with similar branches of neighboring cells. The heart-muscle fibers show a distinct cross and longitudinal striation and possess relatively more sarcoplasm than do the fibers of cross-striated, voluntary muscle tissue. The sarcoplasm surrounds the axially placed nucleus and forms distinct septa, which radiate from the nucleus to the periphery. In this way the muscle fibrillæ are arranged in plates, which also radiate from the nucleus to the periphery. Heart-muscle fibers possess no sarcolemma. Very recent investigations, which seem very conclusive, make it very doubtful whether the lines which have been regarded as the boundary lines of cells are thus to be interpreted, since it has been shown that they bound non-nucleated areas of heart muscle, and further that the striated contractile fibers pass through such lines without interruption, although they show slight alteration in structure and reaction toward staining reagents. According to this view, heart muscle is regarded as a syncitial tissue, the so-called boundary lines representing growth areas. Only very careful embryologic investigation can throw light on the histogenesis and histology of heart muscle.

PLATE 6.—MUSCULAR TISSUES.

FIG. 1.—**Pigmented Connective-tissue Cells from the Human Iris.** × 420.

The preparation was taken from an executed individual.

The figure shows differently formed connective-tissue cells, the protoplasm of which is filled with yellowish-brown and brown pigment granules.

Technic: Chromic acid solution (2 per cent.). Hematoxylin-eosin.

Reference letter: *k*, Nucleus.

FIG. 2.—**Branched Cross-striped Muscle-fibers from the Human Tongue.** × 220.

The preparation was taken from an executed individual.

The figure shows several longitudinally cut tongue muscle-fibers, which fork at their insertion into the fascia linguae.

Technic: Müller's fluid. Hematoxylin-eosin.

Reference letters: *r*, Branchings; *k*, nuclei, some of which are seen in surface view.

FIG. 3.—**Portion of a Longitudinal Section through the Human Heart Muscle.** × 280.

The preparation was taken from one who had been executed.

The figure shows a number of heart-muscle fibers with their anastomoses in longitudinal section; between them is seen the intermuscular connective tissue (perimysium).

Technic: Zenker's solution. Hematoxylin-eosin.

Reference letters for Figs. 3 and 4: *gr*, Boundary lines (these are brought out too clearly in the printing); *k*, nucleus; *pm*, perimysium internum; x, anastomoses.

FIG. 4.—**Portion of a Cross-section through Human Heart Muscle.**

The figure shows the variation in size of heart-muscle fibers, the axially placed nuclei and the radially arranged muscle columns.

Technic and lettering as in Fig. 3.

THE NERVOUS TISSUES.

Nervous tissue, like muscle tissue, is highly differentiated, both as to the structure and the function of its elements. These are, for purposes of description, ordinarily divided into three main groups:

1. Nerve-cells or ganglion-cells.
2. Nerve-fibers.
3. Nerve-supporting tissue or neuroglia.

It is more correct, however, to regard the nerve-cells and the nerve-fibers as parts of the same element, since both histogenetically and structurally considered the nerve-fibers are processes of the nerve-cells. The nerve-

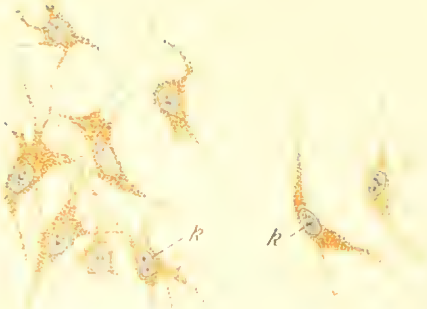
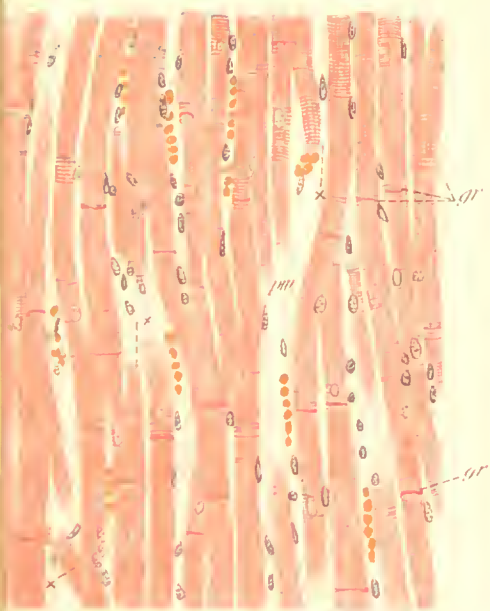


Fig. 1.



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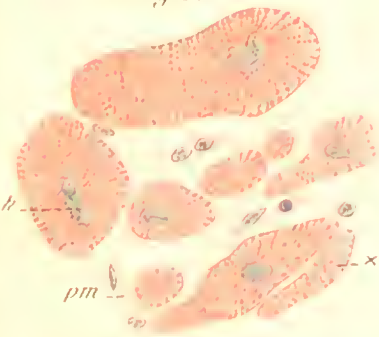

Fig. 4

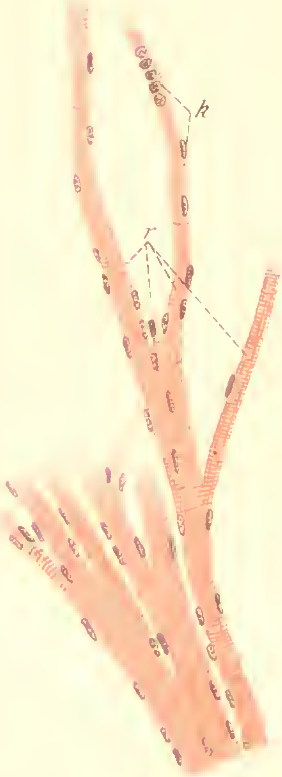

Fig. 2.

cells with their processes, as well as the supporting tissue, the neuroglia, are of ectodermal origin; indeed, they even arise from similar ectodermal cells, although the supporting tissue, when fully developed, is in many respects similar to connective tissue. The essential portions of the nerve-fibers, the axis-cylinders or neuraxes, develop only as processes of the nerve-cells, even when they attain great length. In their course outside of the central nervous system the neuraxes are surrounded by special sheaths, which, with the neuraxes, constitute the nerve-fibers. In this discussion we shall follow the above classification and treat the nerve-fibers separately. The nerve-cells and the axis-cylinder processes or neuraxes, the main constituents of the nerve-fibers, accordingly form together the anatomic units of the nervous system, the so-called *neurones*. A neurone, therefore, consists of (1) the nerve-cell or ganglion-cell with its protoplasmic branches, the dendrites (see page 72); (2) the neuraxis with its collaterals; (3) the terminal branching of the neuraxis.

The "neurone concept" of the nervous system is now very generally accepted. By it is meant that the nervous tissues, like the other tissues of the body, are composed of anatomic units (cells), which are morphologically, pathologically, and, to a certain extent, physiologically independent of each other. The neurones come into relation with each other only by contact. Recent observations have thrown some doubt on the validity of this doctrine; in the strict sense it can no longer be supported, since anastomoses of the terminal arborizations, and even of ganglion-cells, have been shown beyond question.

Nerve-cells occur in the central nervous system, especially in its gray matter, in certain sense organs, as in the retina and olfactory membrane, in the plexuses and ganglia of the cerebro-spinal and sympathetic nervous systems.

The *form* of the ganglion-cells is very variable; yet in many regions there are found nerve-cells of fixed and characteristic morphologic appearance, as in the brain centers and especially in the cerebellum. Some characteristic forms are limited exclusively to certain parts of the nervous system. Besides the spherical cells of certain of the peripheral ganglia, many kinds of polygonal cells are found with many forms of processes.

The ganglion-cells in general are large cells rich in protoplasm, being among the largest cells of the body. Only a few varieties are small and have a small amount of protoplasm. Ganglion-cells consist of protoplasm probably not bounded by a cell membrane and possess a very characteristic nucleus.

The *nucleus* of ganglion-cells is relatively large and is almost without exception spherical. It is poor in chromatin and especially shows very few distinct chromatin fibers, on account of which it has a clear, vesicular appearance. Almost invariably it contains a large, distinct nucleolus.

The *protoplasm* of ganglion-cells is unusually complex and the investigations on this subject are not yet complete. From it arise a varying number of processes. Each ganglion-cell has at least one process, the axis-cylinder process or *neuraxis*, which arises from the cell either directly or by means of a so-called implantation cone. After giving off some collateral branches, this generally becomes at once a nerve-fiber, which is usually medullated. Occasionally, however, the neuraxis divides at once after leaving the cell into its terminal arborization without first becoming a part of a nerve-fiber. Nerve-cells possessing a neuraxis of this type are known as *Golgi's cells* or ganglion-cells of the second type. In addition to the neuraxes, which have few branches, most ganglion-cells have a number of so-called *dendrites;* these, and especially the larger ones, are direct continuations of the protoplasm of the cell and show all the characteristics of the protoplasm of ganglion-cells. The dendrites always branch and generally form an extensive arborization which can scarcely be followed to its end. We will mention here only two functionally important constituents of the ganglion-cell: First, its fibrils, called *neurofibrils.* These form a network in the body of the ganglion-cell and extend into the processes of the cell, and not simply into the nerve processes, but also into the dendrites. They form the conducting part of the nerve-fibers. In the second place there are found in the cell-bodies of nearly all ganglion-cells, especially in the bodies of the larger ones, clusters of granules of different form, which stain readily in certain basic dyes, and are known as *Nissl's bodies* or the *tigroid substance.* They are quite large structures, irregularly polygonal and often elongated and even spindle-shaped, and can be easily recognized under moderate magnification. They occur in the different ganglion-cells in varying number and size, and appear to vary according to the functional activity of the cell and to undergo changes in certain pathologic conditions. The Nissl bodies are also found in the larger dendrites. It should be stated that, according to the views of some authors, the Nissl bodies are not found in the living ganglion-cell, but arise only after death. As they can, however, be recognized in fresh preparations of the central nervous system, this is very improbable.

Larger ganglion-cells, especially the giant-cells of the lower animals (as many fishes), which are recognized with the unaided eye, contain peculiar canals in the protoplasm. In the giant nerve-cells of many fishes true capillaries are found; in others, the canals, which are much smaller and narrower, appear to be intracellular lymph-canals or canaliculi. Among these are the so-called Holmgreen canals and the reticular apparatus of Golgi.

The main forms of nerve-cells are the following (given more in detail in the chapter on the Central Nervous System, page 95):

1. *Spherical ganglion-cells without dendrites and with one neuraxis,* so-called *unipolar* cells; after leaving the cell, however, the neuraxis undergoes a T-shaped division, so

PLATE 7.—NERVE-CELLS.

FIG. 1.—**Two Isolated Multipolar Ganglion-cells from the Human Spinal Cord.** × 160.

The figure shows two isolated ganglion-cells of the spinal cord, with richly branching dendrites; the neuraxes (X) have been torn away.

Technic: Isolation in weak chromic acid solution. Carmin.

FIG. 2.—**Two Multipolar Ganglion-cells from the Lumbar Enlargement of the Spinal Cord of a Child.** × 480.

The preparation was taken from a still-born child.

The figure shows the cell-body and the roots of the dendrites of two ganglion-cells. The protoplasm of these contains numerous intensely stained, irregular granules (tigroid substance).

Technic: Absolute alcohol. Methylene-blue according to Nissl.

Reference letters: *D*, Dendrite; *K*, nucleus; *t*, tigroid substance.

FIGS. 3-5.—**Three Cells from a Human Spinal Ganglion.** × 420.

The preparation was taken from one who had been executed.

The figure shows three spherical cells of different sizes, with their nucleated capsules. One cell contains yellowish-brown pigment.

Technic: Zenker's solution. Hematoxylin-eosin.

Reference letters: *bH*, connective-tissue capsule; *p*, pigment.

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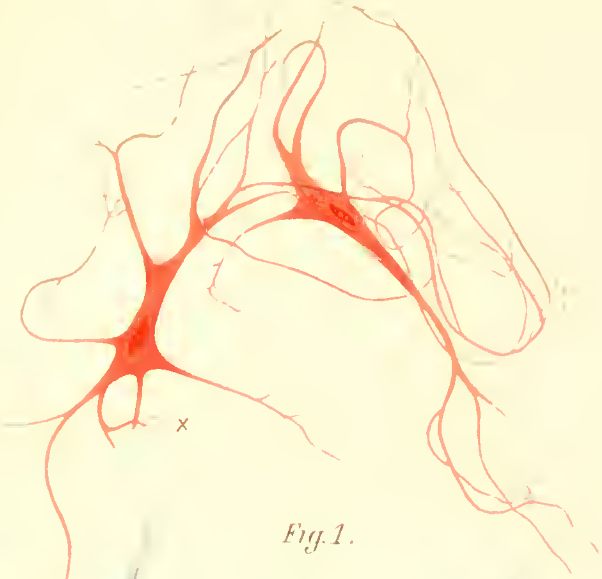
that the cells are really bipolar. This cell form is found in the sensory cranial ganglia and the spinal ganglia.

2. *Spherical* or nearly spherical cells with *one dendrite* and *one neuraxis* arising from opposite ends of the cell, so-called *bipolar* cells. They are found in the retina in the inner granular or ganglion-cell layer and in the ganglia of the acoustic nerve.

3. *Spherical* or nearly spherical cells with *one neuraxis* and several short, fine dendrites which can be demonstrated only by the help of special methods—*multipolar* cells. They are found as the chief constituents of the sympathetic ganglia. When stained after methods which do not bring out the dendrites, these cells resemble the cells of the spinal ganglia.

4. *Large*, irregularly shaped *polygonal* to short spindle-shaped *multipolar ganglion-cells*, with *one neuraxis* and several dendrites which pass in all directions from the cell. To this class belong the multipolar cells of the spinal cord, of the medulla oblongata, of the so-called central gray nuclei and other portions of the brain.



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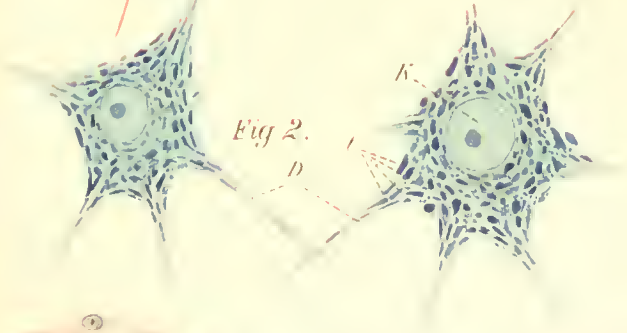

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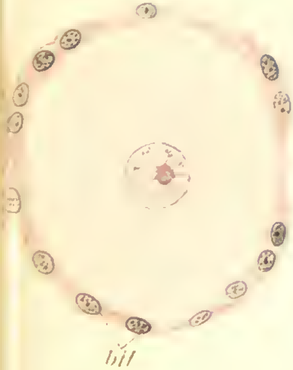

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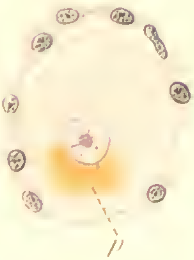

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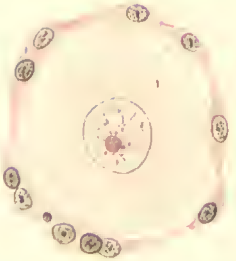


Fig. 5.

5. *Multipolar ganglion-cells* of *regular* form with one neuraxis and with dendrites which arise from the cell-body in a manner which is characteristic for the form of the cell. The main representatives of this group are the pyramidal cells of the cerebral cortex and the Purkinje cells of the cerebellum.

6. *Small multipolar cells with different forms of dendrites,* as certain cells of the granular and molecular layers of the cerebellum, some cell forms of the cerebral cortex, and others.

7. The *multipolar Golgi cells,* which have already been mentioned and which are characterized by the *peculiar behavior of their neuraxes.*

(b) **Nerve-fibers.**—The chief constituent of all nerve-fibers is the neuraxis of the nerve-cell, which forms the so-called axis-cylinder of the nerve-fiber. Each nerve-fiber must therefore have an axis-cylinder. Some nerve-fibers consist of *naked axis-cylinders* (fibers of the olfactory nerve). The *axis-cylinder* has a distinctly fibrillar structure (neurofibrils) and appears in the form of a larger or smaller cylinder or band in the center of the fiber, running uninterruptedly its whole length. The neurofibrils are united by an interfibrillar substance, the *neuroplasm.* This, the conducting portion of the fiber, is surrounded by the medullary sheath and the sheath of Schwann or the neurilemma. The origin of the former is doubtful, but the latter is of mesenchymal origin.

Most of the cerebro-spinal fibers, and hence most of the nerve-fibers of the body, possess both medullary sheath and neurilemma outside of their course in the central nervous system, but within this only a medullary sheath. These nerve-fibers are called *medullated* and also, on account of their appearance in the fresh condition, dark-bordered or doubly contoured fibers. They are of very variable size, varying between 1 μ and 20 μ. In contrast to these we have the *non-medullated* fibers, also known as pale or Remak's fibers, which consist only of axis-cylinder and neurilemma; the latter is especially delicate in non-medullated fibers. They occur especially in the sympathetic system and to a less extent in the realm of the central nervous system. The *medullary sheath* shows interruptions at regular intervals. These appear in the form of rings, the so-called *nodes of Ranvier*. At the nodes the medullated nerve-fiber consists only of axis-cylinder and neurilemma, since the latter bends in to the axis-cylinder, which here shows a biconical enlargement.

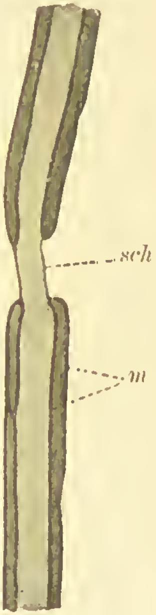


Fig. 21.—Portion of a medullated nerve-fiber from man. × 375. The figure shows a node of Ranvier of the medullary sheath. Lantermann's segments may also be recognized. *m*, Medullary sheath; *sch*, node of Ranvier.

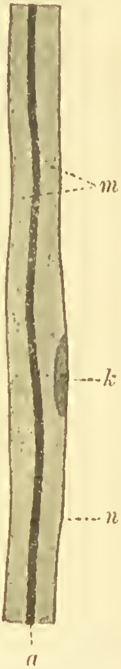


Fig. 22.—Portion of a human medullated nerve-fiber. Nucleus and axis-cylinder stained with carmin. × 375. *a*, Axis-cylinder; *k*, nucleus; *m*, medullary sheath; *n*, neurilemma.

Nodes of Ranvier are found at regular intervals, varying in different fibers, but in general the interval is greater in large fibers than in small ones. The nodes are always found at the point of division of a medullated nerve-fiber. The portion of a fiber between two nodes is called an internodal segment. In large fibers the segments measure about 1 mm., while in small fibers they are 0.1 mm. and even less.

The *medulla* or *myelin* of the medullated nerve-fiber, the constituent of the medullary sheath, is a substance which refracts light strongly and is similar to fat; like the latter, it is blackened by osmic acid. It is very sensitive to reagents. With nearly every fixing method the medullary sheath has a different appearance in microscopic preparations. Certain portions of the medullary sheath can be differentially stained, after the use of special methods of fixation. The Weigert stain for medullary sheaths is based on this principle.

In the living nerve the medullary sheath is quite homogeneous, but readily changes and presents segments separated from each other by clear fissures which are obliquely placed. These segments are known as Schmidt-Lantermann segments and are also visible in nerves after treatment with osmic acid. Their significance is not known; it is quite probable that they are artefacts. On the death of the nerve-fiber the myelin undergoes coagulation changes, resulting in the formation of globules, especially at the broken end of the fiber.

The *sheath of Schwann* (neurilemma) is a thin, structureless membrane of connective-tissue origin, which contains a few long nuclei within a relatively large amount of protoplasm. The nuclei are found on the inner surface of the neurilemma and only *one* nucleus falls within each internodal segment. The nuclei of the segments alternate in their position. The non-medullated nerve-fibers, with the exception of those of the olfactory nerves which do not have special sheaths of Schwann, but bundles of which

Fig. 23.—Portion of a cross-section of the spinal cord of a new-born child, treated by the Golgi method. × 120. The figure embraces the region between the central canal and the base of the anterior median fissure and shows the condition of the ependyma cells and their processes, as well as two astrocytes. *A*, Astrocyte with long processes; *ep*, ependyma. single cells, with processes blackened; *fma*, base of the anterior median fissure.

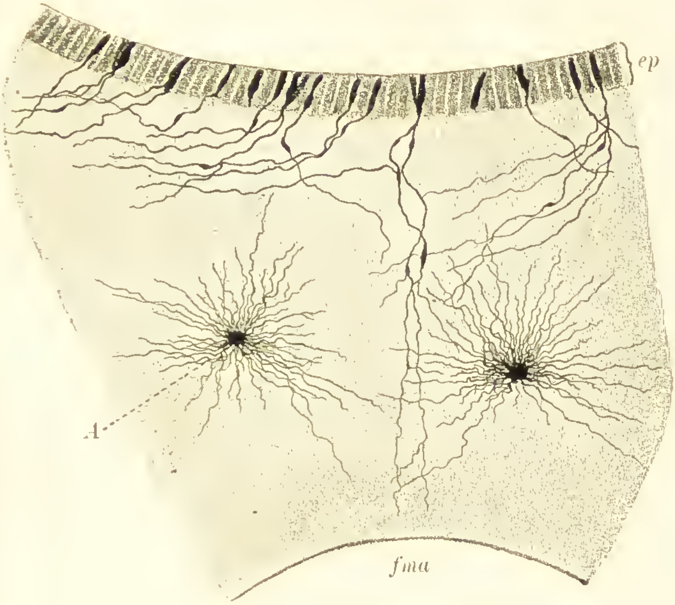
Fig. 24.—Two short-rayed astrocytes from the gray substance of the cerebral cortex of man. Golgi's silver method. × 250. The figure shows two typical glia cells of the short-rayed type. Golgi method. *C*, Capillary.

Fig. 25.—Two long-rayed astrocytes from a section through the medulla oblongata of a new-born child. × 110.

retain special connective-tissue sheaths, consist only of the axis-cylinder and the neurilemma, which is especially thin and delicate. Their structure is, therefore, the same as that of the medullated fibers, except that the medullary sheath is lacking. (See Plate 17, Fig. 2.)

(c) The Neuroglia.—The *neuroglia*, the supporting tissue of the nervous system, is found only in the central nervous system and in the optic chiasm, optic nerves and retina, and olfactory nerves. Owing to the fact that of the several methods now at hand for staining neuroglia differentially, no two give identical results, the views concerning this tissue are still at variance. The investigation of the neuroglia is further rendered more difficult by the fact that it occurs in a pure form in only a few places, but is generally associated with nerve-cells and nerve-fibers. In tissue treated by the chrome-silver method of Golgi, all neuroglia elements appear as *cells with processes*, the cells and processes forming the framework of the central nervous system.

In tissues treated after the complicated differential staining methods developed by Weigert, Mallory, and Benda, the neuroglia appears in the form of independent fibrils, which are distinguished from the fibrils of fibrous connective tissue by their chemical reaction, and which are either entirely separated from the neuroglia cells, or pass through the protoplasm of the latter. It is probable that originally



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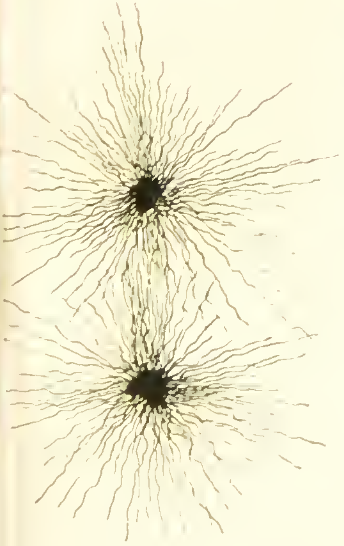

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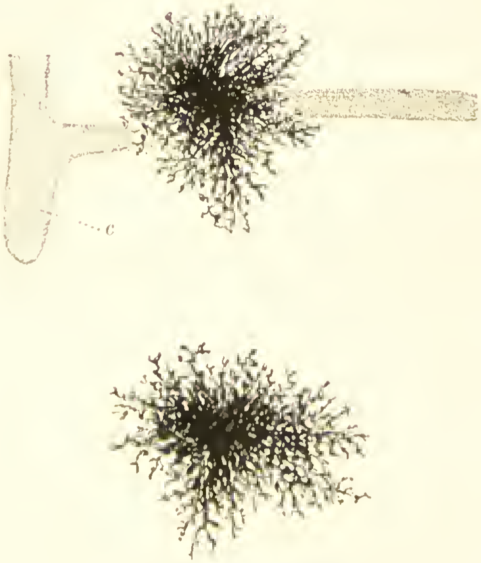

Fig. 24.

all neuroglia fibers are formed in and by the protoplasm of neuroglia cells and later become independent of the cells. Investigators who have made use of the chrome-silver method of Golgi in their study of the neuroglia reach the following conclusions: They distinguish two essentially different cellular elements of the neuroglia: (1) The so-called *ependyma cells*, cubic to cylindric epithelial cells which line the cavities of the central nervous system; (2) stellate cells, the so-called *spider cells* or *astrocytes.*

Of all the elements of the central nervous system, the *ependyma cells* are the least differentiated, retaining their embryonal character longest. In preparations of the spinal cord treated after the ordinary staining methods, these elements appear as simple columnar cells, now and then showing cilia. After the use of the *Golgi* method we recognize that each ependymal cell has a long process which divides many times and in the embryonal condition extends to the surface of the spinal cord. This character of the ependyma cells is most distinct in the spinal cord, and the processes of the cells extend to the base of the anterior median fissure and to the posterior septum.

The *spider cells* or the *astrocytes* of the neuroglia are characterized by numerous fine, either branched or unbranched processes. The astrocytes are found, not like the ependyma cells, limited to certain regions of the central nervous system, but are very generally distributed throughout the gray and white matter of the central nervous system, the optic and portions of the olfactory nerves. They originate partly from the ependyma cells which wander toward the periphery, partly from other still undifferentiated cells of the embryonal central nervous system, so-called spongioblasts. All glia cells lie originally in what is later the gray matter and reach the white matter only secondarily.

The astrocytes are divided into the *short-rayed* or astrocytes with a few short branching processes, and *long-rayed astrocytes,* which have many fine, long processes, nearly or quite unbranched; the two types of glia cells, however, are not sharply separated from each other. The former occur only in the gray substance, the latter in both the gray and the white substance. In course and arrangement their processes are fitted to their environment. Their long processes often form dense networks. Many short-rayed astrocytes appear related to the blood-vessels (capillaries) of the central nervous system, presenting an appearance as though inserted into the wall of the vessels.

Investigators who have made use of special methods for differentially staining the neuroglia have found that what appear as processes of the ependyma cells and astrocytes are in reality sharply contoured fibers, which are either wholly independent of the neuroglia cells or, if in relation with the protoplasm of the cells, pass through it without losing their identity and without suffering interruption. In such preparations it may be seen that the neuroglia fibers pass over and under and along the sides of the neuroglia cells, often following protoplasmic processes of the cells, but are in no way continuous with the protoplasm of the neuroglia cells. This view of the structure of neuroglia tissue is more in accord with the recent investigations on this subject.

(B) THE MICROSCOPIC ANATOMY OF THE ORGANS.

I. THE SKELETAL SYSTEM.

Under the skeletal system we shall consider the bones, the joints, and the ligaments.

During life the *bones* consist not only of osseous tissue, but also of soft parts. The constituents of bone are as follows:

1. Osseous tissue—(*a*) compact, (*b*) spongy.
2. The osseous membrane or the periosteum.
3. The bone-marrow—(*a*) red, (*b*) yellow.
4. The articular cartilage.
5. Blood-vessels and nerves.

The **osseous tissue** forms the main mass of the entire bone and shows a characteristic arrangement. It is classified under the connective tissues, and especially under that group which is characterized by the structure and arrangement of its ground substance. The *ground substance* of bone is hard, as a result of the lime salts deposited in it (calcium phosphate, calcium carbonate, and some calcium fluorid). The lime salts are distributed in the ground substance in the form of molecules and are not recognizable by optical means. It is thought that the lime salts are deposited in the gelatin-yielding fibrils of the ground substance, as well as in the interfibrillar substance. Owing to this intimate relation of ground substance to the mineral salts, a bone which has been macerated or even burned, that is deprived of all its organic constituents, has the same form that it would have had if it had been decalcified or deprived of its calcium salts. In consequence of this we can investigate the structure of bone in preparations of decalcified and of macerated bone.

The cellular elements of osseous tissue, known as *bone-cells*, or, according to the older designation, bone corpuscles, lie in spaces of the ground substance, the so-called *bone-spaces* or *lacunæ.* The latter are most easily seen in thin pieces of macerated bone. In such preparations the lacunæ are filled with air and, under the microscope, appear black in transmitted light and white in reflected light. The lacunæ are elongated, flattened spaces, from which fine canals proceed, the *canaliculi.* The canaliculi of neighboring spaces anastomose with each other. The *bone-cells* are found in the lacunæ and assume the shape of the spaces in which they are found. They send processes into the canaliculi into which they probably extend but a short distance. It is, however, difficult to make a positive statement concerning this point. In the earlier stages of bone development there are undoubted anastomoses of neighboring cells, but later probably not.

Compact as well as spongy bone consists of *lamellæ.* In the spongy bone these show no regular arrangement, while in the compact bone there is a very typical arrangement of the lamellæ, dependent on the arrangement of the *blood-vessels* of the bone. The medium-sized and small blood-vessels run in canals, known as the *Haversian canals.* The greater portion of compact bone consists of lamellæ of ground substance arranged concentrically around these canals; the lamellæ are known as the *Haversian lamellæ.* The lacunæ lie at the boundaries of two lamellæ, so that the long axis of the cell or lacuna coincides with that of the Haversian canal, the canaliculi passing through the substance of the lamella to the next row of lacunæ. The innermost row of lacunæ is united by canaliculi with the Haversian canal itself; the lacunæ are here very much curved to correspond with the course of the lamellæ, especially when small Haversian canals are involved. The lacunæ of neighboring lamellæ usually alternate.

Besides the Haversian lamellæ, we distinguish two other systems of lamellæ: (1) Those which run parallel to the inner and outer surfaces of the bone, the so-called *ground lamellæ* or circumferential lamellæ; (2) those which run between the Haversian systems without relation to them, but frequently parallel to the ground lamellæ, the *interstitial lamellæ.* In sections of decalcified bone or in ground preparations of macerated bone, cut Haversian lamellæ are met with, which may be confused with the interstitial lamellæ. This very regular arrangement of bone substance into lamellæ with interlamellar cell-spaces is not present in very thin layers of bone, as for instance in the cementum of the tooth, where the cell-spaces have an irregular arrangement.

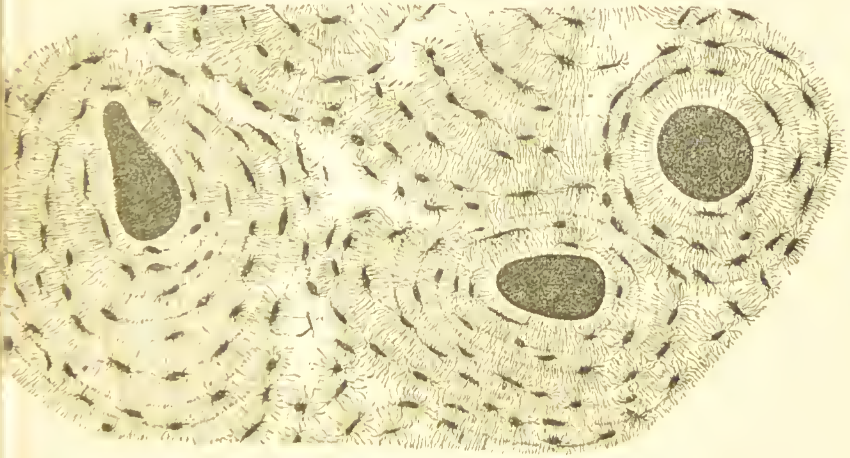

Fig. 26.—Portion of a cross-section of a metacarpal bone of man. × 150. The figure shows three Haversian canals with the lamellæ belonging to them. The lacunæ and canaliculi are easily recognized.

Occasionally some of the ground lamellæ are lacking, so that, for instance, the Haversian lamellæ are joined directly to the periosteum. The larger blood-vessels of bone lie in canals which show no concentric lamellar systems. These are called *Volkmann's canals.* They gradually change into the *Haversian canals* surrounded by lamellar systems, without any definite line of demarcation. In the neighborhood of the periosteum the external circumferential lamellæ show uncalcified connective-tissue

Fig. 27.—Portion of a cross-section of a decalcified human radius. × 48. The figure shows the lamellar systems of compact bone, as well as some trabeculæ of spongy bone. *agl*, External ground lamellæ; *igl*, internal ground lamellæ; *il*, interstitial lamellæ; *hl*, Haversian lamellæ; *p*, periosteum; *sp*, trabeculæ of spongy bone.

fibers from the periosteum, which penetrate the lamellæ transversely or obliquely and are known as *Sharpey's fibers*.

The *periosteum* consists of fibrous connective tissue. It is divided into an external fibrous layer which is rich in blood-vessels, but contains few cells, and an inner cellular layer containing few fibers and blood-vessels. The latter layer often contains osteoblasts (see page 87).

The *articular cartilages* are usually of the hyaline variety (see page 49).

The *ligaments* are fibrous structures consisting of dense white fibrous connective tissue, with the exception of certain ligaments (nuchæ, subflava), which are composed of elastic fibers. The symphyses or sutures, on the other hand, consist of very loose connective tissue. The labra glenoidolia are not composed of hyaline cartilage, but consist of very dense fibrous connective tissue, which often shows the structure of white fibro-cartilage. The joint capsules and tendon sheaths consist of two layers—an external fibrous layer of dense fibrous tissue, and an inner synovial stratum, which is lined on its inner surface by endothelial cells, though these are not always in a continuous layer (see page 42).

The *bone-marrow* is divided into two classes—the red and the yellow. In the adult, the yellow marrow predominates in the marrow canals and larger marrow spaces of the long bones. It consists mostly of adipose tissue. The red bone-marrow is found in the smaller marrow spaces of spongy bone and is very rich in blood-vessels; the capillaries are partly devoid of endothelial walls. The red bone-marrow consists of a delicate reticulum of white fibrous and reticular connective tissue, in the meshes of

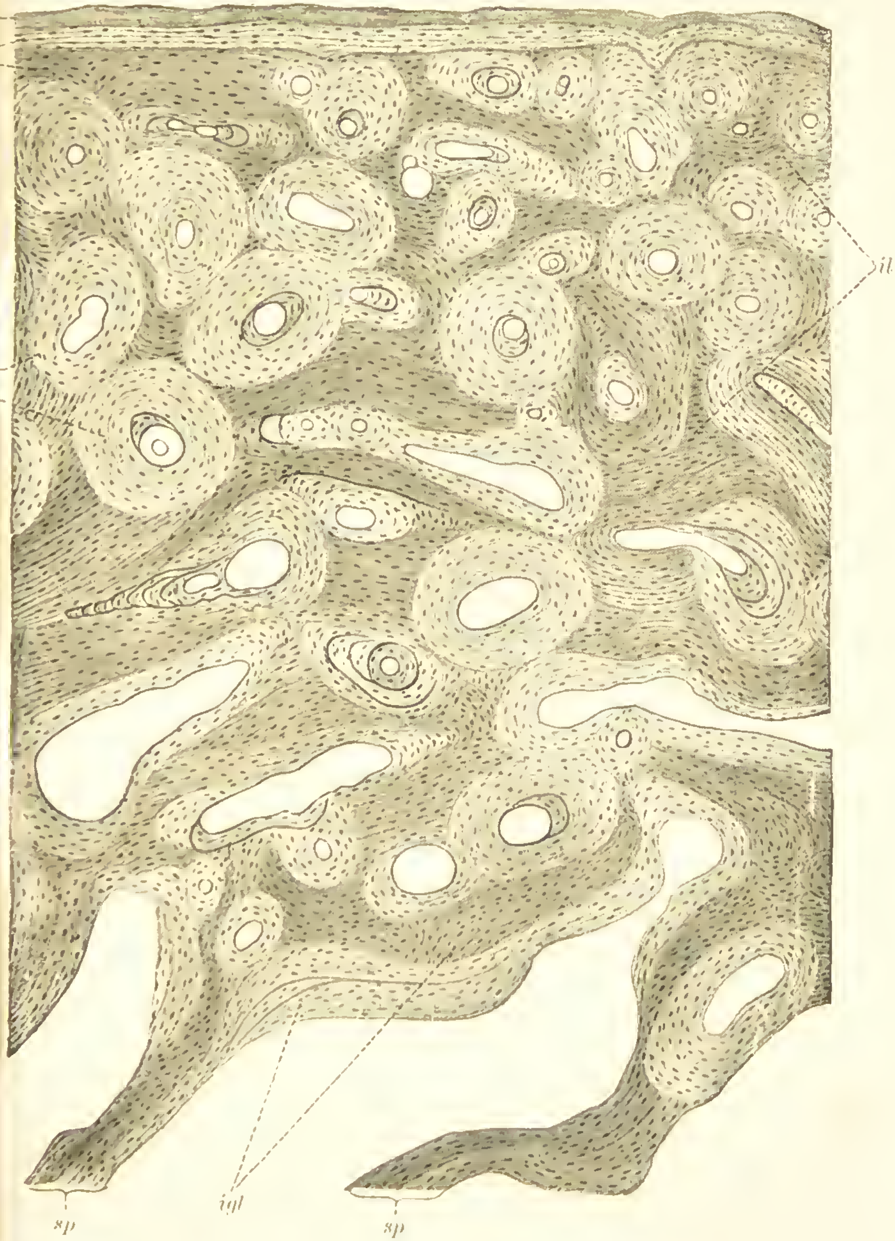

Fig. 27.

ich are found lymphocytes and leukocytes, myelocytes,
nt-cells, and the *developmental forms of red blood-cells*
e page 62).

The *blood-vessels* of bone are distributed partly in the
riosteum; others penetrate through the nutrient canal to
e bone-marrow. In the bone substance the larger ves-
s lie in the Volkmann's canals, the smaller ones in the
aversian canals. The lymph paths begin with the peri-
llular spaces of the lacunæ and canaliculi of bone and
ntinue as perivascular spaces following the blood-vessels.

The nerves of bone are found principally in the perios-
um, where they terminate as free sensory endings or
cinian corpuscles. Vasomotor fibers accompany the
od-vessels to the bone-marrow. The bone substance
elf is devoid of nerves.

BONE DEVELOPMENT.

The embryonal anlagen of the osseous skeleton are
rtly of hyaline cartilage and partly of white fibrous
nnective tissue. Accordingly we distinguish bone pre-
rmed in cartilage or endochondral bone, and primary
d secondary connective-tissue bone, also known as intra-
mbranous bone.

The process of *bone development* in the bones *preformed*
cartilage is the more complicated, because in this, two
ocesses are taking place at the same time: first, that of
richondral ossification, which originates from the peri-
ondrium of the cartilaginous anlagen of the skeleton;
d second, the *endochondral* ossification. The latter takes
ace in the cartilaginous anlagen of the skeleton and is
companied by the breaking down of the cartilage. With
gard to the manner of bone formation the two processes
e essentially the same; nevertheless, the result of the
ne formation in endochondral ossification gives a dis-
ctly different picture from that in perichondral ossifica-
on, so that the osseous tissue arising from endochondral

PLATE 8.—BONE DEVELOPMENT.

Longitudinal Section of the Last Two Phalanges of a Finger of a Five-month Human Embryo. × 15.

The figure shows the distinction between the processes of endochondral and perichondral ossification. Bone tissue appears red, cartilage bright blue, calcified cartilage dark blue. The epiphyses are still entirely cartilaginous.

Technic: Müller's fluid with formalin. Hematoxylin-eosin.

Reference letters: *cK*, Endochondral bone with remains of calcified cartilage matrix; *Kn*, cartilage; *M*, marrow space with marrow-cells and blood-vessels; *pK*, perichondral or intramembranous bone.

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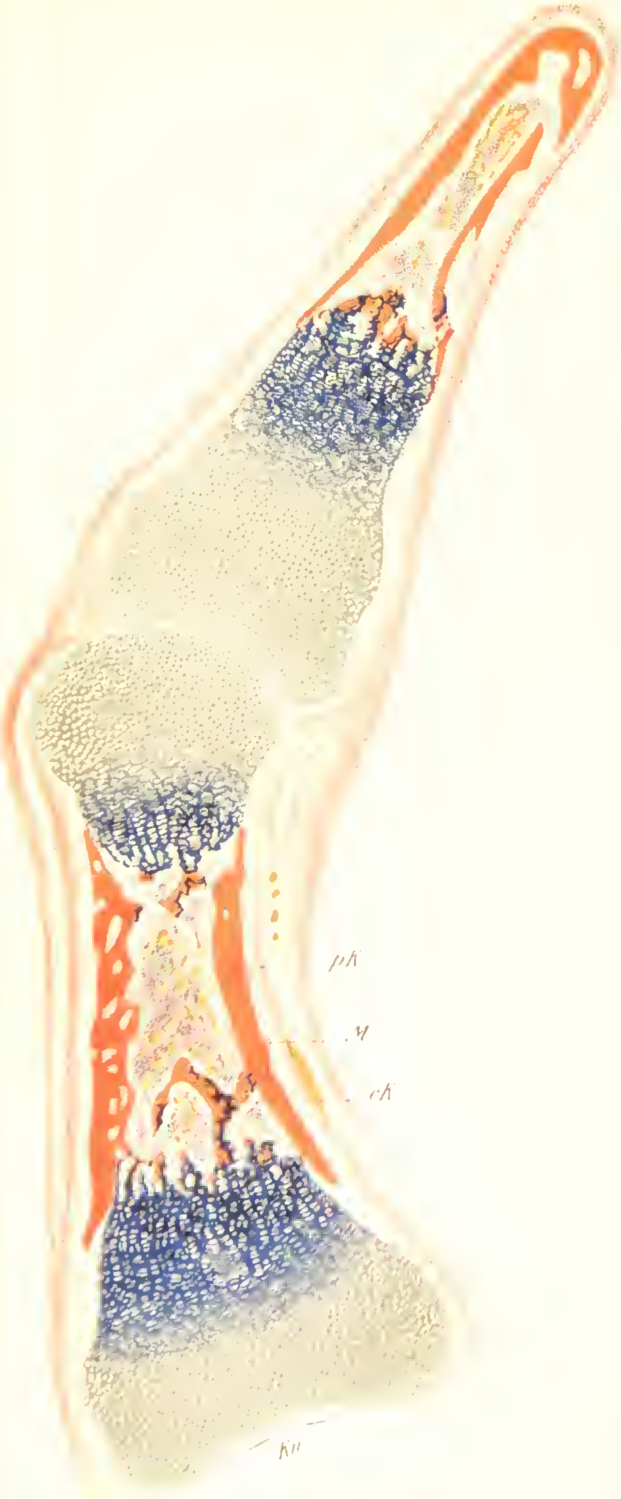
ossification is easily to be distinguished from that arising by perichondral ossification.

The *perichondral ossification* begins somewhat *earlier* than the endochondral; in the middle of what is later the diaphysis of a long bone, a layer of embryonic bone is formed by the perichondrium, while at the same time and in the same region the cartilage begins to calcify.

Calcium salts are deposited in the ground substance of the cartilage, the cartilage spaces increase in size, and finally there is a shrinking of the cartilage cells, which is soon followed by the death of the cells. In the region of the calcification of the cartilage, the further growth of cartilage ceases. In consequence of this, some time after the beginning of ossification the cartilaginous portion of the skeleton appears as if constricted in the region of the zone of calcification. Cell divisions still take place after the beginning of calcification, but no new cartilage spaces are formed, so that several cells lie in one of the enlarged cartilage spaces before they degenerate.

The formation of *endochondral* bone is initiated by the penetration of a blood-vessel from the periosteum into the calcified cartilage. The way through the calcified ground substance of the cartilage is opened for the blood-vessel by polynuclear giant-cells called *osteoclasts*, which have the power of disintegrating calcified cartilaginous substance as well as bone (see page 91). The osteoclasts break down the enlarged cartilage spaces, so that only

Tab. 8.



remains of the intervening walls, consisting of calcified cartilage matrix, are left. The calcified cartilage matrix stains a dark bluish-violet with hematoxylin, while the uncalcified ground substance stains a light violet. In this way anastomosing primary *marrow spaces* develop in the bone anlage, which are at first small. These primary marrow spaces are filled with cells derived from the inner or osteogenetic layer of the embryonic periosteum (perichondrium) and are known as *osteoblasts*. Certain of these cells differentiate into the cells of what is later the red bone-marrow. Between them numerous blood-vessels are found. Around the remains of the calcified cartilage matrix, which project freely into and bound the newly formed marrow spaces, lie the osteoblasts, rich in protoplasm, oval or low cylindric in form; these, especially where they are arranged in rows, give the impression of epithelium; they are known as osteoblasts or bone-formers, because they are the cells which deposit the osseous substance. Through the activity of the osteoblasts, osseous matrix still free from cells is formed around the remains of the cartilage matrix. This, therefore, always contains within it, even when the formation of the bone is farther advanced, calcified cartilage matrix in the form of serrated lines and trabeculæ, which are easily distinguishable in microscopic preparations by their color. When the osteoblasts first deposit osseous substance, this is free from cells. Gradually, however, osteoblasts are surrounded by young osseous substance; they then lose their bone-forming function and become fixed bone-cells. Only the spongy bone tissue is developed by endochondral bone formation.

The process of *perichondral ossification* is very similar; it has already begun when calcification occurs in the cartilaginous portion. On the inner surface of the perichondrium at this time is found a tissue rich in cellular elements, known as the osteogenetic tissue. This contains, on the side turned toward the bone anlage, a single layer

PLATE 9.—BONE DEVELOPMENT.

Cross-section through a Forearm Bone of a Six-month Human Embryo. × 45.

Within the periosteal ring the figure shows bone formed by endochondral and by perichondral ossification. On one side the latter is markedly developed, while on the other side it is entirely absorbed, so that here the endochondral bone reaches the periosteum. The endochondral bone contains remnants of calcified cartilage matrix and is separated from the perichondral bone by a blue boundary line of the same substance. On the outer surface of the endochondral bone a larger resorption surface is found with giant-cells in the lacunae. The perichondral bone shows on its outer surface an almost continuous layer of osteoblasts. It already forms a compact mass with Haversian canals.

Technic: Müller's fluid. Carmin-hematoxylin.

Reference letters: *bg*, Blood-vessels of bone-marrow; *eK*, endochondral bone; *gl*, boundary line between endochondral and perichondral bone; *Hk*, Haversian canals; Hk_1, Haversian canals in process of formation; *M*, bone-marrow; *ob*, osteoblasts; *p*, periosteum; *pK*, perichondral bone; *Rz*, giant-cells.

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of very prominent osteoblasts, which deposit osseous substance on the calcified and constricted diaphyseal portion of what is later endochondral bone. Thus, bone in this region is apposed from *without*. In its earlier stages perichondral bone is developed in a manner similar to that of endochondral bone formation; like the latter, perichondral bone is at first free from cells; as the process proceeds, the osteoblasts are inclosed, other osteoblasts continuing the further deposition of osseous tissue, even at a time when the endochondral bone is still being formed.

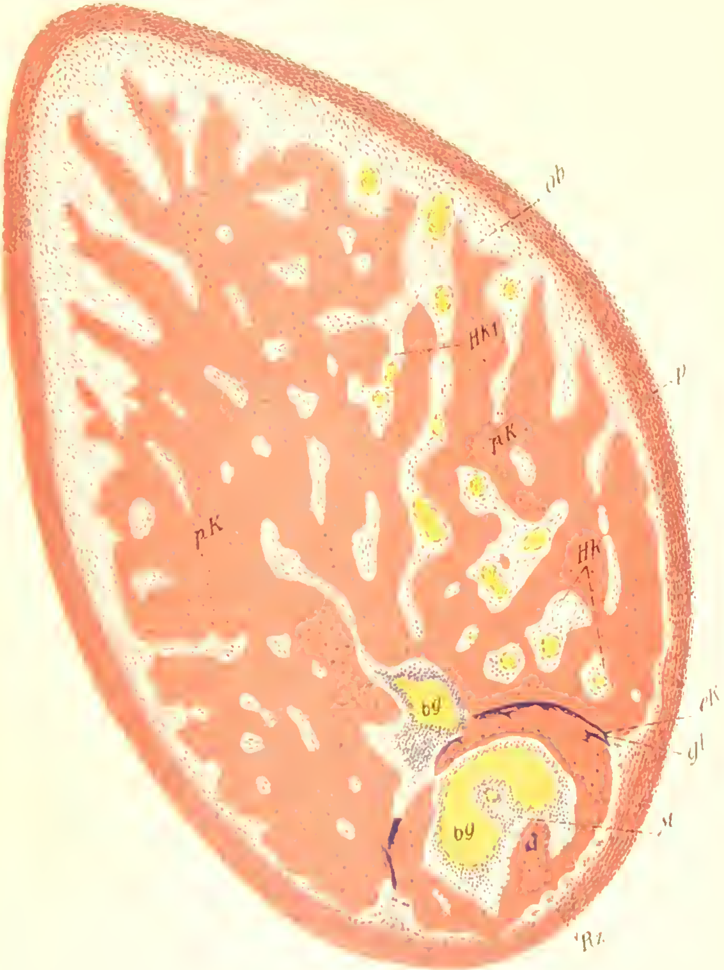
PLATE 10.—BONE DEVELOPMENT.

Cross-section of the Upper End of the Diaphysis of the Femur of a Six-month Human Embryo. × 15.

The figure shows a large number of small trabeculae of endochondral bone with the blue stellate figures of calcified cartilage matrix within them. Between these are found numerous marrow spaces with marrow-cells and blood-vessels. A thin, incomplete layer of perichondral bone surrounds the endochondral bone, separated from it by a boundary line of calcified cartilage matrix.

Technic: Müller's fluid. Carmin-hematoxylin.

Reference letters: *bg*, Blood-vessels; *ek*, endochondral bone; *gl*, boundary line between endochondral and perichondral bone; *p*, periosteum; *pK*, perichondral bone.


ob
HK1
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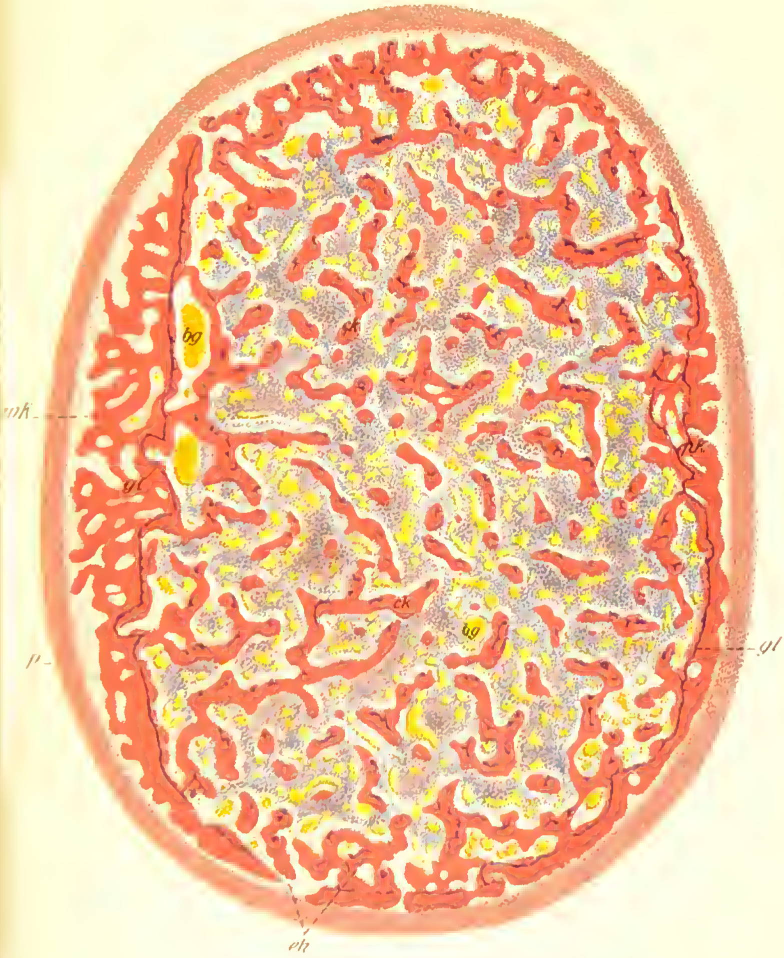
bg
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ck
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wk.
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p
eh

The boundary line between the two kinds of bone can be easily recognized by a fine line of calcified cartilaginous matrix. The perichondral bone, of course, contains no bits of cartilage matrix, as it is deposited outside of the cartilaginous portion of the skeleton.

The apposition of new perichondral bone does not take place by the simple deposition of osseous material on the new bone which was formed earlier and the consequent thickening of the original layers of bone; but trabeculæ of bone are developed, which become confluent and thus inclose osteogenetic tissue. The cavities thus formed contain blood-vessels and also on their inner surfaces layers of osteoblasts, which constantly produce new osseous substance and thus diminish the size of the original cavity. When the diminution in size has gone on until the cavity is very little larger than the blood-vessel which it contains, the osteoblastic activity ceases, the uninclosed osteoblasts probably again becoming fixed connective-tissue cells, and a Haversian canal is formed. In this way the perichondral bone formed assumes gradually the structure of ordinary compact bone. Perichondral ossification results in the formation of compact bone. The greater portion of the whole skeleton is therefore of fibrous tissue origin. Up to the time of birth there is still a relatively large amount of endochondral bone. During the first and second years of life the greater portion of this is absorbed and replaced by perichondral bone; this is true of even much of the spongy bone. As perichondral bone develops from the outside,—that is, by apposition,—it does not show a row of osteoblasts toward the marrow cavity.

The formation of intramembranous bone follows a similar course to that of perichondral bone. A layer of osteoblasts is arranged around the calcifying bundles of connective tissue; numerous anastomosing trabeculæ of bone are thus formed, inclosing blood-vessels and forming Haversian canals, quite as in perichondral ossification.

The process of ossification, as we have described it, is

PLATE 11.—BONE DEVELOPMENT.

FIG. 1.—**Portion of a Longitudinal Section of a Metacarpal Bone of a Five-month Embryo.** × 50.

The figure represents the region of endochondral ossification of an embryonal metacarpal bone and shows the changes which the cartilage undergoes before its dissolution. Outside in the perichondrium is a layer of perichondral bone.

Technic: Müller's fluid with formalin. Hematoxylin-eosin.

Reference letters: *eK*, Bone formed by endochondral ossification; *Kn*, cartilage; Kn_1, zone in which the cartilage cells are arranged in rows; Kn_2, zone of enlarged cartilage cells and calcification of ground substance; *KnR*, remains of calcified cartilaginous matrix; *M*, marrow; *pK*, bone formed by perichondral ossification; *Rz*, giant-cells (osteoclasts).

FIGS. 2–6.—**Processes of Bone Formation and Bone Resorption in the Lower Jaw of a Seven-month Human Embryo.** × 420.

Technic: Müller's fluid with formalin. Hematoxylin-eosin.

Fig. 2.—Young bone trabeculæ just forming. Osteoblasts are inclosed by bone substance and thus changed to bone-cells.

Fig. 3.—Giant-cells in the resting stage in the connective tissue.

Fig. 4.—Two active giant-cells in a small (almost resorbed) piece of bone tissue.

Fig. 5.—Three giant-cells on the border of a large piece of bone. One cell lies in a lacuna, the second is somewhat separated from the bone, and the third is absorbing a projecting point of bone.

Fig. 6.—Giant-cell in a lacuna. The nuclei of the cells lie at the side away from the resorption surface.

Reference letters for Figs. 2–6: *c*, Capillary; *Kns*, osseous tissue; *knz*, bone-cells; *obl*, osteoblasts; obl_1, osteoblasts changing to bone-cells.

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also characterized as the *neoplastic* type, in opposition to a method of bone formation which occurs only in very few places in the human body, in which there is a direct transformation of the cartilage into bone, that is without precedent degeneration of the cartilage, and which is known as the *metaplastic* type. The only region where this method of bone formation takes place to any extent is in the ossification of the articular processes of the lower jaw. It would appear that here the cartilage cells change directly into bone-cells. During the growth of bones, the absorption of osseous tissue goes on hand in hand with the formation of new bone tissue; in this way the marrow canals and marrow spaces are enlarged. The absorption

Tab. II.

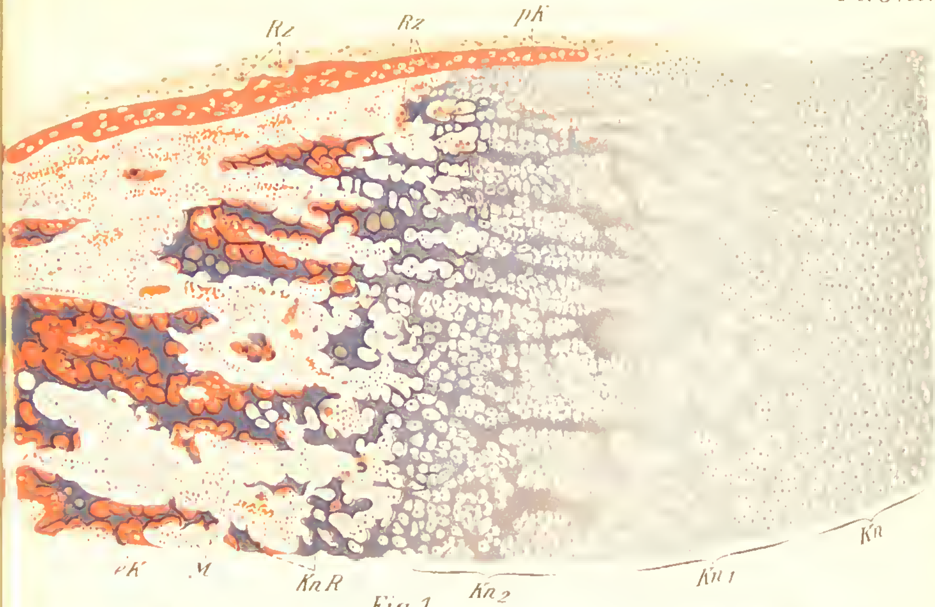


Fig. 1.

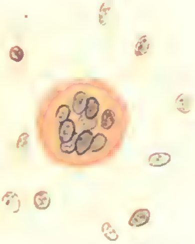


Fig. 3.

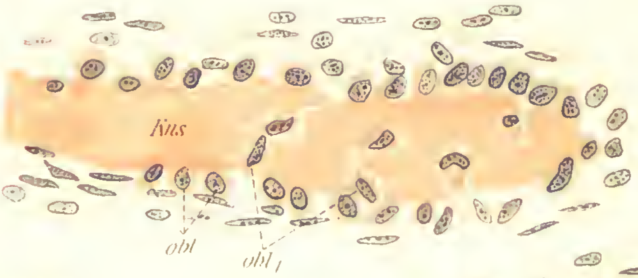


Fig. 2.

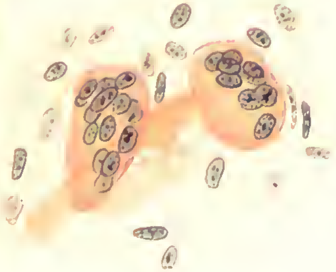
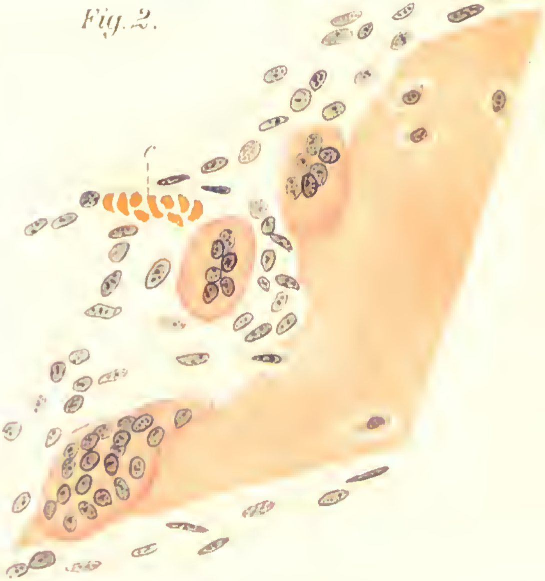


Fig. 4.



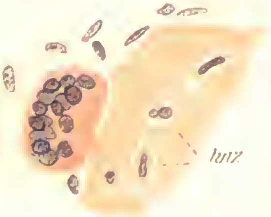


Fig. 6.

Fig. 5.

of the bone already formed is brought about through the agency of special cells, known as *giant-cells* or *osteoclasts*. They are large, spherical, polynuclear cells in the resting stage, such as are found also in the bone-marrow. The osteoclasts apply themselves to the bone to be absorbed so that they fit the form of the surface; thus they often surround splinters of bone which are to be resorbed. Some time after the application a pit is seen in the bone, which often exactly corresponds to the form of the osteoclast; these depressions are known as *Howship's lacunæ*. Where larger resorptions take place, the osteoclasts often lie close together, and, forming pit after pit and dissolving the bridges which separate them, may dissolve large surfaces of bone. Not simply during the entire time of the growth of bone, but also in later life, areas are found where bone is being resorbed.

II. THE ORGANS OF THE MUSCULAR SYSTEM.

The principal organs of the muscular system are the muscles, tendons, and fasciae.

The **muscles** consist of a collection of transversely striated muscular fibers, which are separated into subdivisions by strands of connective tissue. The external, more markedly developed connective tissue is called the *perimysium externum*. It sends strands of connective tissue, known as *perimysium internum*, into the interior of the muscle, which inclose irregular spaces and bound muscle bundles of different sizes. The terminal processes of the perimysium finally surround each single muscle-fiber forming the *endomysium*. The perimysium is quite rich in elastic fibers. At the nodal points of the perimysium lie the larger blood-vessels and nerve-trunks of the muscle and usually the large sensory nerve endings known as the neuromuscular spindles. The latter are, however, not found in all the muscles of the body; they are lacking in

PLATE 12.—MUSCLE.

FIG. 1.—**Portion of a Cross-section of the M. Omohyoideus of Man.** × 40.

The tissue was fixed two and one-half hours after death.

The figure shows the arrangement of the muscle bundles, of the perimysium, of the blood-vessels, nerves, and of the neuromuscular spindles (the curved line to the right is the free surface of the muscle).

Technic: Zenker's fluid. Hematoxylin-eosin.

Reference letters: *a*, Artery; *bg*, blood-vessel (vein); *msp*, neuromuscular spindle; *n*, nerve; *pme*, perimysium externum; *pmi*, perimysium internum.

FIG. 2.—**Cross-section of Neuromuscular Spindle from the M. Omohyoideus of Man.**

The figure gives the picture of a transversely cut neuromuscular spindle with the neighboring transversely sectioned muscle-fibers. The spindle, composed of a connective-tissue sheath, small muscle-fibers and nerves, lies in the perimysium internum. Fine strands of the latter penetrate between the single muscle-fibers surrounding the spindle.

Technic, etc., as in the preceding figure.

Reference letters: *bdg*, Connective-tissue sheath of the spindle; *M*, muscle-fibers of the spindle with axial nuclei; *m*, transversely striated muscle-fiber in cross-section; *n*, nerve-fiber; *pm*, perimysium of the single muscle-fibers.

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the extrinsic eye muscles, in the intrinsic muscles of the tongue, in the muscles of the face, and in certain other smaller muscles.

The *neuromuscular spindles* are long fusiform structures, which are generally arranged in the direction of the long axis of the muscle and usually lie in the perimysium separated from the other muscle-fibers. The neuromuscular spindle consists of a connective-tissue capsule, composed of from four to eight concentric lamellæ of fibrous connective tissue, within which are found four to twenty small muscle-fibers rich in sarcoplasm, known as the intrafusal fibers. In them we may recognize a proximal polar, an equatorial, and a distal polar region. In the proximal and distal polar regions the intrafusal muscle-fibers present the structure of striated muscle-fibers of the red variety. In the equatorial region they are rich in sarcoplasm and contain numerous nuclei, which are axially

Tab. 12.

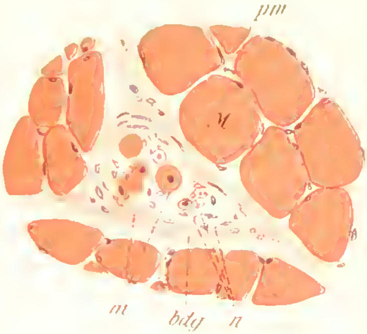

Fig. 2.

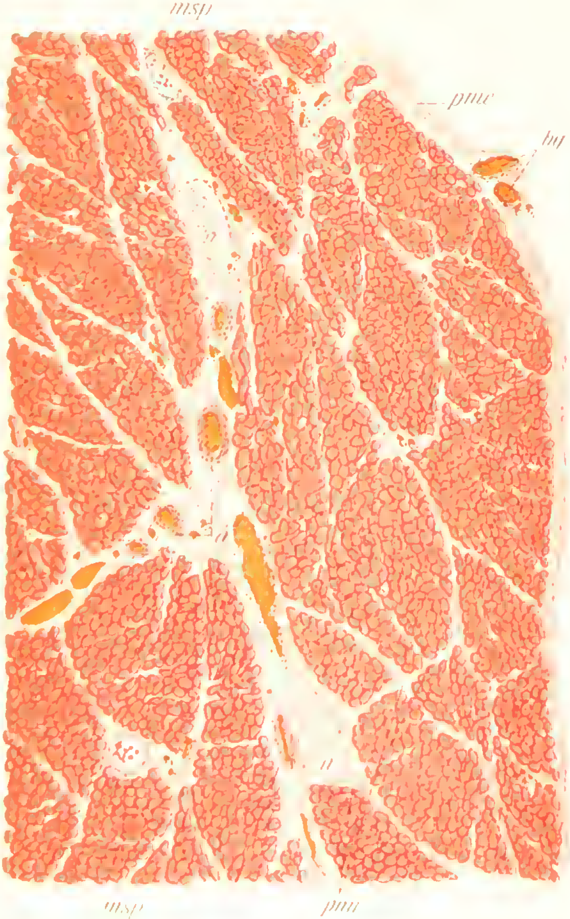

Fig. 1.

placed, the fibrillar structure appearing as a thin layer about the periphery of the fibers. Surrounding the intrafusal fibers there is found a thin layer of connective tissue known as the axial sheath, and between this and the capsule there is found a large lymph-space, bridged by connective-tissue trabeculæ, to which the name of periaxial space is given. The intrafusal muscle-fibers of the spindle are not connected with other muscle-fibers, but begin and end free in the sheath derived from the perimysium. The neuromuscular spindles contain numerous nerves, which show very characteristic endings (see page 113). They are sensory organs, which subserve muscular sense.

The *blood-vessels* of muscle are very numerous. The larger trunks run in the coarser strands and nodal points of the perimysium. The branches pass into the muscle bundles and each single muscle-fiber is surrounded by small capillaries, which form long meshes around the muscle-fiber. The nerves of muscle are numerous. They are medullated and non-medullated; the former comprise partly motor and partly sensory fibers. The motor fibers end on the muscle-fibers themselves. Each muscle-fiber contains at least one and generally several motor endings (see page 109). The sensory fibers go in part to the neuromuscular spindles, the adventitia of blood-vessels, and the connective tissue sheaths of muscles; others pass to the neurotendinous end-organs found in the tendons. The non-medullated fibers end on the blood-vessels.

The **tendons** are connective-tissue organs, which are composed of very regular parallel bundles of connective tissue. The bundles, which are composed of formed connective tissue poor in elastic fibers, are designated as *tendon bundles* (also called tendon bundles of the smallest order, or primary tendon bundles, or tendon fasciculi). Between the tendon bundles lie the stellate *tendon cells*, connective-tissue cells, which, with their processes, surround the tendon bundles, since they anastomose with the processes of neighboring cells. In smaller mammalia

Fig. 28.—Cross-section of a human tendon. × 32. The preparation was taken from one who had been executed. The figure gives the general structure of tendon. Reference letters for Figs. 28 and 29: *bdg*, Strands of connective tissue; *bg*, blood-vessels; *Sb*, larger tendon bundles, bounded by strands of connective tissue; *Sz*, tendon cells.

(rat, mouse) the tendon cells possess a somewhat regular, rectangular body with lamellar processes, the so-called winged tendon cells.

Each tendon consists of a collection of tendon bundles, which are held together by strands of areolar connective tissue. The connective tissue which surrounds the whole tendon, and which is known as the external peritendineum, sends processes into the interior of the tendon, forming the internal peritendineum, which separates and surrounds irregularly shaped groups of tendon bundles, forming the so-called *secondary tendon bundles*, of which each larger tendon contains a number.

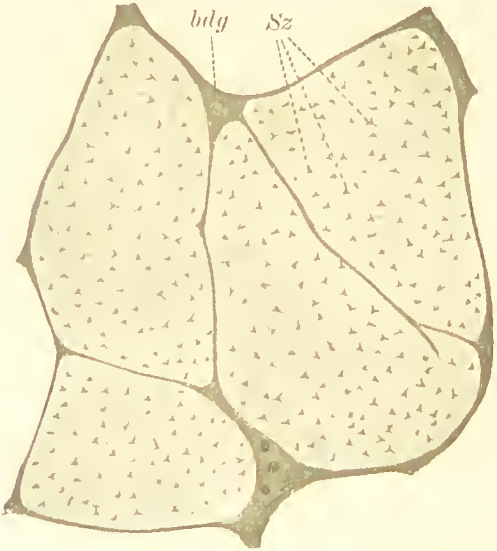

Fig. 29.—A portion of the section of tendon reproduced in Fig. 28, under higher magnification (× 64). The figure shows the tendon cells within the secondary tendon bundles.

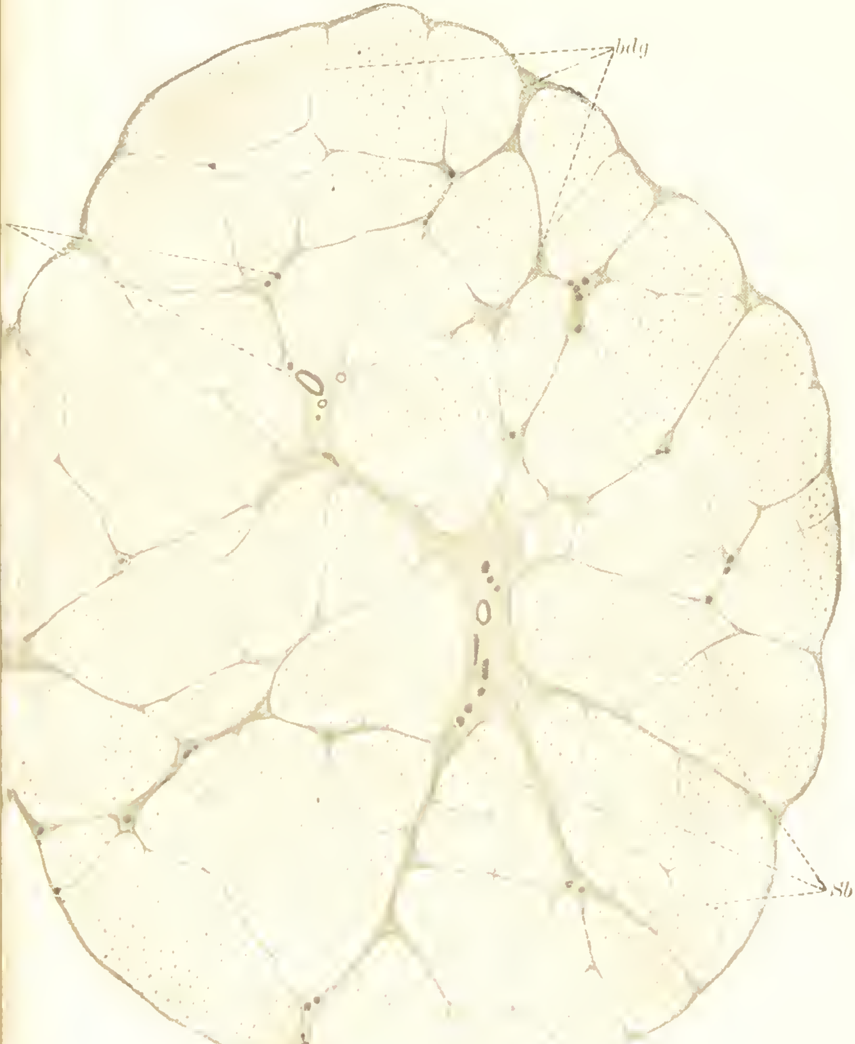

Fig. 28.

The tendons are very poor in blood-vessels, the larger branches of which are found at the nodal points of the internal peritendineum. On the other hand, tendon has a very rich supply of sensory nerves; certain of the sensory nerve-fibers pass to the *Vater-Pacinian corpuscles;* others terminate in free sensory endings, while still others end in the so-called *neurotendinous spindles* (see page 113) situated at the boundary line between muscle and tendon.

Fibrous membranes, aponeuroses, and fasciæ have a structure quite similar to that of tendons.

III. ORGANS OF THE NERVOUS SYSTEM.

1. THE CENTRAL NERVOUS SYSTEM.

The space allotted to this section does not permit an extended description of the structure of the entire central nervous system, and especially not of the course of the fibers contained therein. It is our purpose to describe briefly the structure of the spinal cord, of the medulla oblongata, of the cerebellar and cerebral cortex, so far as the elements of the nervous system (see under nervous tissues, page 70), by their combination, make up the structure of the parts to be considered. In regard to the relations of the course of the nerve-fibers, of the topography of the several parts, etc., the text-books of anatomy, and particularly the special texts on nervous anatomy, must be consulted. The topography of the spinal cord and medulla (olives) has been included in the legends accompanying Plates 13–15.

The gray matter of the **spinal cord** and of the medulla, as well as of the entire brain, consists of neuroglia, ganglion-cells, and scattered medullated nerve-fibers; the white matter consists of medullated nerve fibers devoid of the sheath of Schwann, between which neuroglia is found. Processes of the pia mater of the spinal cord run into the

PLATE 13.—SPINAL CORD.

Cross-section of the Human Spinal Cord in the Region of the Cervical Enlargement. × 8.

The preparation was taken from an adult and was fixed two and one-half hours after death.

Technic: Müller's fluid. Sodium carminate.

The figure gives a topographic picture of the spinal cord, the distribution of the gray and of the white matter, the distribution of the columns and of the pia mater.

Reference letters: *bg*, Blood-vessels; *ca*, anterior horn of gray matter; *cma*, anterior commissure; x, region of the obliterated central canal; *cp*, posterior horns of gray matter; *fa*, funiculus anterior or anterior column; *fam*, anterior median fissure; *fc*, funiculus cuneatus or the column of Burdach; *fg*, funiculus gracilis or the column of Goll; *fl*, funiculus lateralis or lateral column; *fr*, formatio reticularis; *pm*, pia mater; *ra*, anterior, ventral, or motor root-fibers; *rp*, posterior, dorsal, or sensory root-fibers; *sg*, substantia gelatinosa of Rolando; *sp*, posterior median septum.

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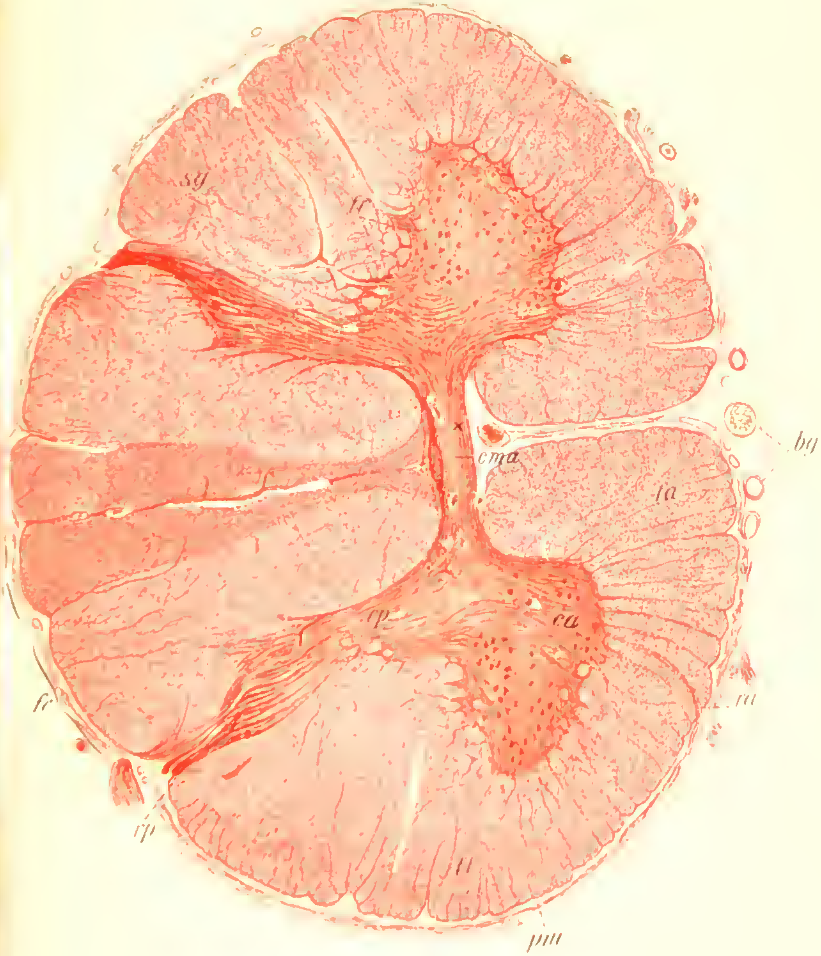
white matter, partially dividing it into areas known as columns. The nerve-fibers of the white substance run within the columns, for the most part in the direction of the long axis of the spinal cord; larger bundles running transversely are found only in the ventral and dorsal root-fibers. The structure of the white substance in its whole breadth is very uniform. The neuroglia cells are scattered here and there throughout the white matter, and the neuroglia fibers course between the nerve-fibers. A thicker layer of glia fibers is found at the surface of the spinal cord under the pia mater.

The gray matter of the spinal cord presents a more complicated structure than the white matter. Its constituents have in general the following relations: The *ganglion-cells* of the spinal cord are, without exception, multipolar cells, but of different sizes. The largest cells are the *motor cells* of the *anterior horns*, which are usually arranged in several groups. The neuraxis of each cell passes immediately into one of the nerve-fibers of the anterior or ventral root. The cell-body is large, its branches, especially at their origin from the cell-body, being large and richly branched (see page 74). The other nerve-cells


sg
fr
cma
bg
fa
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pm

of the spinal cord are smaller and their dendrites are not so well developed. As their neuraxes run into the columns of the white matter, from which they may give off at different levels collaterals which enter the gray matter, these cells are called column cells. The neuraxes of certain of the column cells pass through the gray matter to the opposite side of the cord; these are known as commissural cells. The column and commissural cells lie scattered through the gray matter, partly in groups, as for instance the *dorsal nucleus* or column of Clarke, situated at the base of the posterior horn and especially well developed in the lower dorsal and upper lumbar regions. Certain of the cells of the posterior horns have a neuraxis which does not pass into a nerve-fiber, but breaks up immediately into many branches; these are the so-called Golgi's cells (see page 75).

The *nerve-fibers* of the gray matter show a very complicated arrangement. They are found in all parts of the gray matter, partly singly, partly in small groups, and only exceptionally in more compact bundles. They comprise the beginnings of the motor roots, which, soon after their origin, receive medullary sheaths, further dorsal root-fibers, which enter the gray substance through the apices of the posterior horns and pass in this through the substantia gelatinosa Rolandi and the region of the dorsal nucleus to the anterior horn into the region of the large motor ganglion-cells, forming the so-called reflex collateral fibers; others come in contact with the collaterals of column cells. In the white commissure medullated fibers cross to the opposite side of the spinal cord.

The *neuroglia* of the gray matter is found in the form of ependymal cells lining the central canal or its remains, in case the central canal is obliterated, and as neuroglia cells and fibers, scattered throughout the gray matter. Special collections of neuroglia cells and fibers are found around the *central canal*, where they form a neurogliar mass entirely free from nerve-cells and almost entirely

PLATE 14.—SPINAL CORD.

Cross-section of the Human Spinal Cord at the Level of the Lumbar Enlargement (two-thirds of the section shown). × 15.

The tissue was fixed two and one-half hours after death.

The figure shows two-thirds of a transverse section of the spinal cord with the surrounding pia mater. The medullated nerve-fibers are dark blue, the nuclei red. We see the relation of the medullated nerve-fibers to the gray substance and the white substance.

Technic: Müller's fluid. Weigert-Pal's method for staining the medullary sheaths. Alum-carmin.

Reference letters: *caa*, Anterior white commissure; *Ce*, remains of the obliterated central canal; *fma*, anterior median fissure; *gl*, external glia sheath; *Gz*, ganglion-cells of the anterior horn; *nd*, nucleus dorsalis; *pm*, pia mater; *Ra*, anterior or ventral root-fibers; *Rp*, posterior or dorsal root-fibers; *sg*, substantia gelatinosa of Rolando; *smp*, posterior median septum.

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free from nerve-fibers. The substantia gelatinosa, on the other hand, contains no excess of glia elements.

The *blood-vessels* of the spinal cord enter the nerve substance from the pia mater; the largest trunks are branches of the anterior spinal artery, which penetrates the cord from the base of the median fissure. The white matter is very poor in blood-vessels, while the gray matter is very vascular, being especially rich in capillaries.

The **cerebellar cortex** has a very characteristic structure different from that of all other parts of the brain. It surrounds the white matter of the cerebellum, which con-

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PLATE 15.—MEDULLA OBLONGATA.

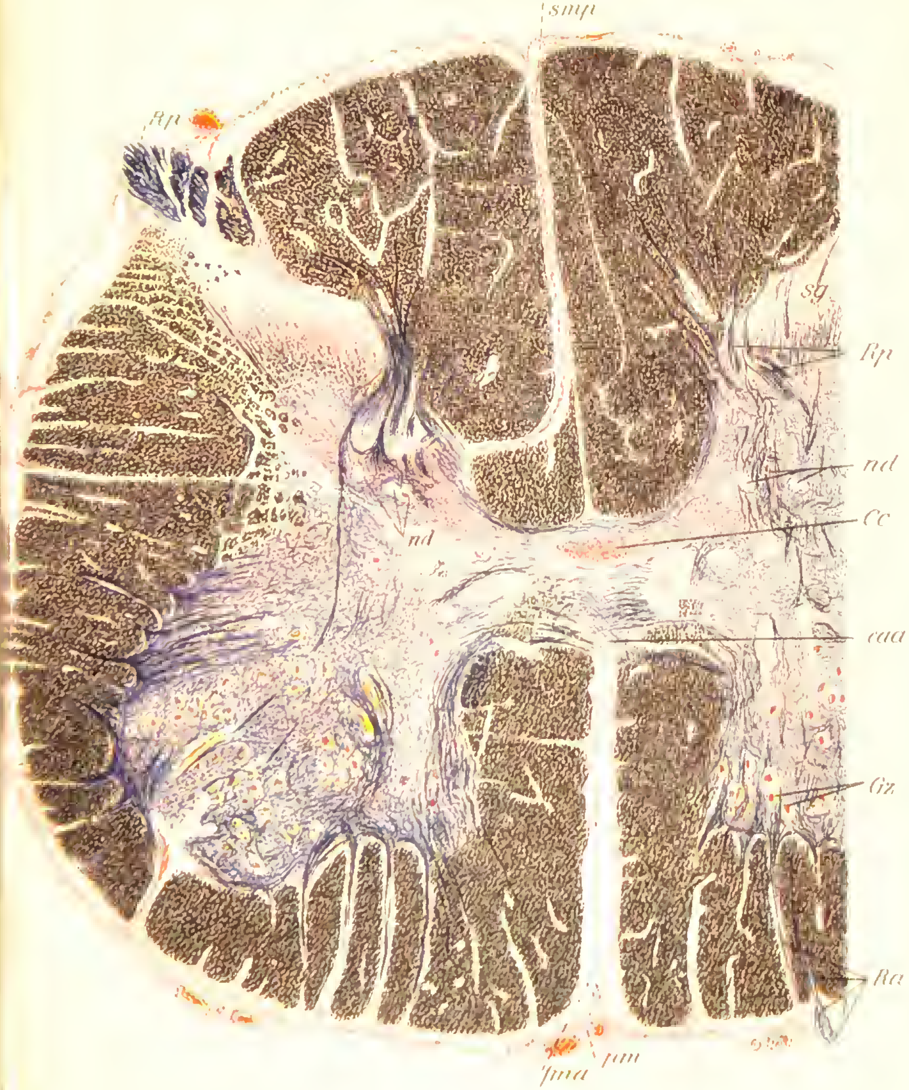
Half of the Cross-section of the Human Medulla Oblongata in the Region of the Olives. × 6.

The preparation was taken from an adult.

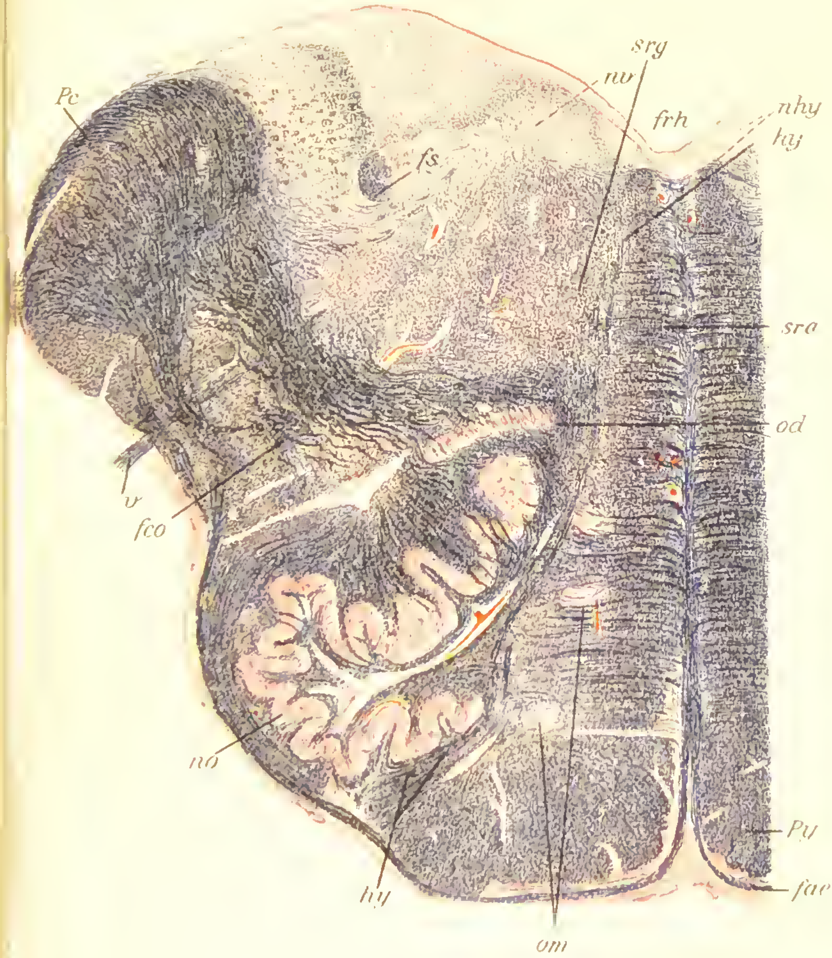
The figure gives a picture of the structure of the medulla oblongata.

Technic: Müller's fluid. Weigert-Pal's method for staining the medullary sheaths. Alum-carmin.

Reference letters: *fae*, Fibræ arciformes externæ; *fco*, fibræ cerebello-olivares; *frh*, fossa rhomboidea; *fs*, fasciculus solitarius; *hy*, nervus hypoglossus; *nhy*, nucleus nervi hypoglossi; *no*, nucleus olivaris; *nv*, nucleus nervi vagi; *od*, oliva dorsalis; *om*, oliva medialis; *Pc*, pedunculus cerebelli; *Py*, pyramid; *sra*, substantia reticularis alba; *srg*, substantia reticularis grisea; *v*, vagus nerve.


smp
Rp
sg
Rp
nd
Cc
nd
caa
Gz
Ra
pma
pm

Tab. 15.



sists of medullated nerve-fibers and glia elements, and which, in the form of rays, forms the arbor vitæ. Structurally considered, the gray matter of the cerebellar cortex

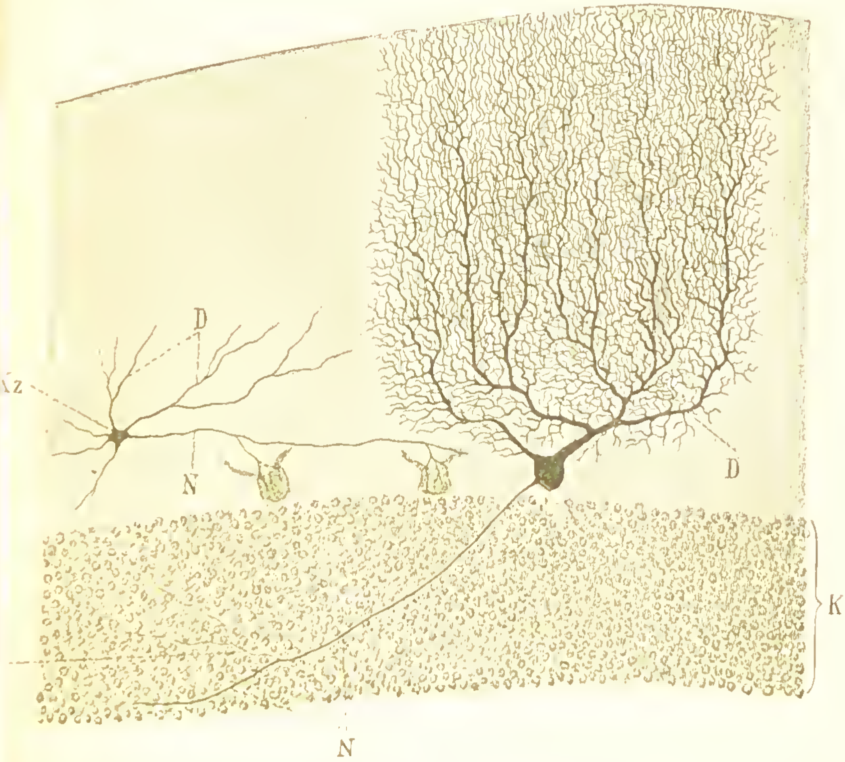


Fig. 30.—Portion of a transverse section of the human cerebellar cortex stained by the Golgi method. × 100. The figure is combined from two preparations: At the right, a cell of Purkinje; at the left, a basket cell (nerve process of the latter and bodies of the two Purkinje cells are somewhat diagrammatic). *C*, Collaterals; *D*, dendrites; *K*, granular layer; *N*, neuraxis.

consists of two layers, which are distinguishable macroscopically—the inner *granular* or *rust-colored layer* and the outer *molecular* or *gray layer*, between which is found a layer of ganglion-cells.

PLATE 16.—CEREBELLUM AND HEART.

FIG. 1.—**Portion of a Transverse Section of the Human Cerebellum.** × 20.

The figure gives a general picture of the structure of the cerebellum.

Technic: Müller's fluid. Sodium carminate.

Reference letters: *bg*, Blood-vessels of pia mater; *lm*, lamina medullaris, layer of medullated nerve-fibers; *stc*, stratum cinereum, or molecular layer; *stgr*, stratum granulosum; *stg*, stratum of ganglion-cells.

FIG. 2.—**Portion of a Transverse Section of a Papillary Muscle of the Human Heart.**

.The preparation was taken from one who had been executed.

The figure gives a picture of the structure of the heart-wall. × 125.

Technic: Müller's fluid. Hematoxylin-eosin.

Reference letters: *bdg*, Intermuscular connective tissue; *en*, endothelium; *end*, endocardium; *my*, myocardium.

The cerebellar cortex, like the gray nuclei, is formed of nerve-cells, nerve-fibers, and neuroglia.

The arrangement of the *nerve-fibers* of the cerebellar cortex, the majority of which are medullated, is very simple. In the granular zone the medullated fibers course between the small ganglion-cells. At the border of the molecular layer we find a somewhat prominent layer of horizontal fibers, which, still medullated, extend for some distance into the molecular layer, in the outer zone of which all the nerve-fibers lose their medullary sheaths. The medullated fibers of the cerebellar cortex are partly the collaterals of the neuraxes of Purkinje cells (see page 101), partly fibers from the brain, which enter through the pedicle of the cerebellum and end in the cerebellum.

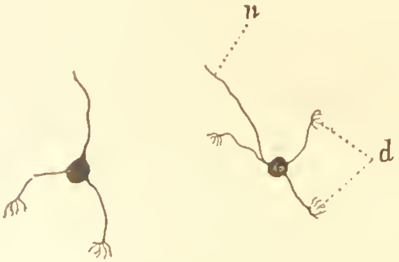


Fig. 31.—Two small granular cells of the human cerebellar cortex, treated by Golgi's method. × 330. *d*, Dendrites; *n*, neuraxis.

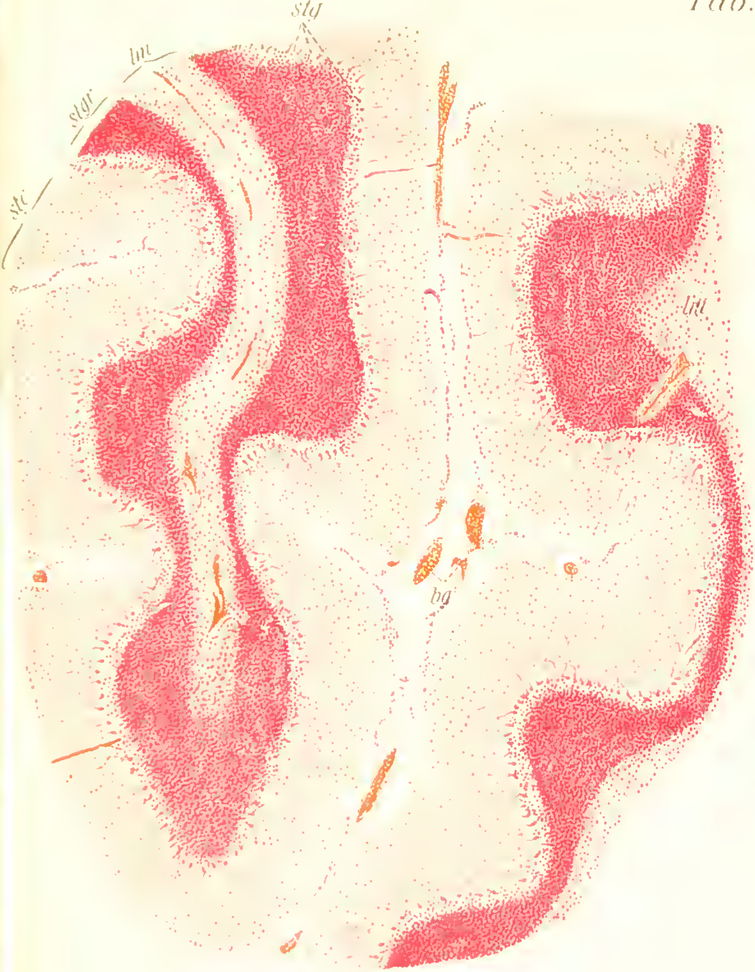


Fig. 1.

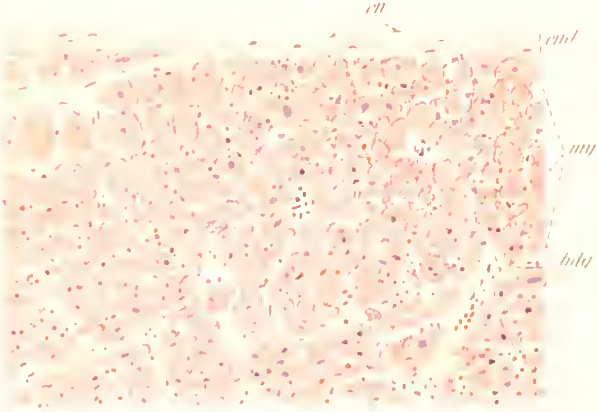


Fig. 2.

The *nerve-cells* of the cerebellar cortex show the greatest possible variety in size and form. The *cells of Purkinje* are the most characteristic and at the same time the largest.

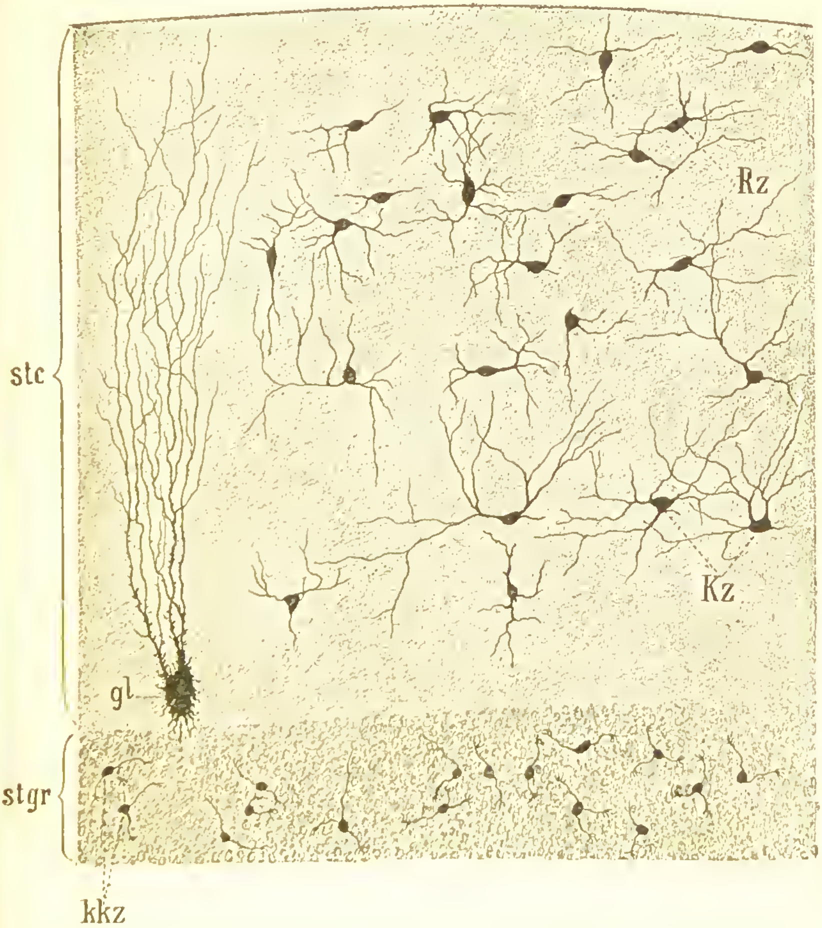


Fig. 32.—Portion of transverse section of the human cerebellar cortex treated by the Golgi method. × 140. The figure shows the small granular cells in the granular layer; in the molecular layer are shown small cortical cells and basket cells. *gl*, Glia cell of molecular layer; *Kz*, basket cell; *kkz*, small granular cell; *Rz*, small cortical cell; *stc*, stratum cinereum or molecular layer; *stg*, stratum granulosum.

PLATE 17.—CEREBELLUM, SYMPATHETIC GANGLION.

FIG. 1.—**Part of a Transverse Section through a Portion of the Cerebellum.** × 30.

The figure shows the lamination of the cerebellum and the distribution of the medullated nerve-fibers.

Technic: Weigert's stain for medullary sheaths.

Reference letters: *bg*, Blood-vessels; *lm*, lamina medullaris; *stc*, stratum cinereum; *stg*, stratum gangliosum; *stgr*, stratum granulosum.

FIG. 2.—**Transverse Section through a Small Sympathetic Ganglion.**

The preparation was taken from an executed criminal.

The figure shows an entire small ganglion, surrounded by a connective-tissue sheath, with nerves entering, from the neighborhood of the seminal vesicle. The ganglion-cells, surrounded by nucleated capsules, have two and even three nuclei.

Technic: Zenker's solution. Hematoxylin-eosin.

Reference letters: *Bdg*, Connective-tissue sheath; *Gz*, ganglion-cells; *N*, entering non-medullated nerve-fibers in longitudinal section; N_1, non-medullated nerve-fibers in cross-section.

Their bodies lie in a single layer at the boundary of the granular and molecular layers, although really in the latter, constituting the layer of ganglion-cells. Their dendrites, generally two in number, branch after the manner of a wall-fruit tree, into very fine and closely crowded fibers, which extend through the entire thickness of the molecular layer, often reaching to the surface of the cortex. At the surface of the convolutions the dendrites pass off from the cell-body at an acute angle, but toward its base the angle becomes gradually more obtuse, until at the root of the convolution the dendrites pass out in almost opposite directions. The neuraxes of the cells of Purkinje pass through the granular layer, where they give off recurrent collaterals, and, as medullated nerve-fibers, pass into the medullary substance, with the fibers of which they intermingle.

Besides the cells of Purkinje and their branches, the molecular layer contains two other types of cells, between which transition forms are said to occur. They are known as *basket cells* and *small cortical cells*. Both are quite small multipolar ganglion-cells. The basket cells have a long neuraxis, which runs parallel to the boundary between the

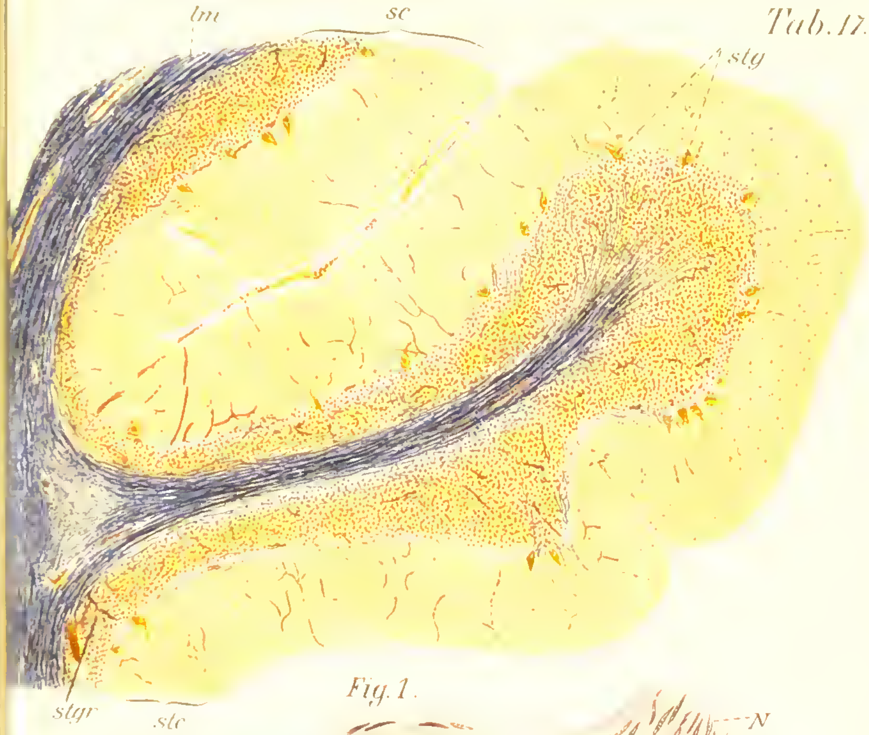
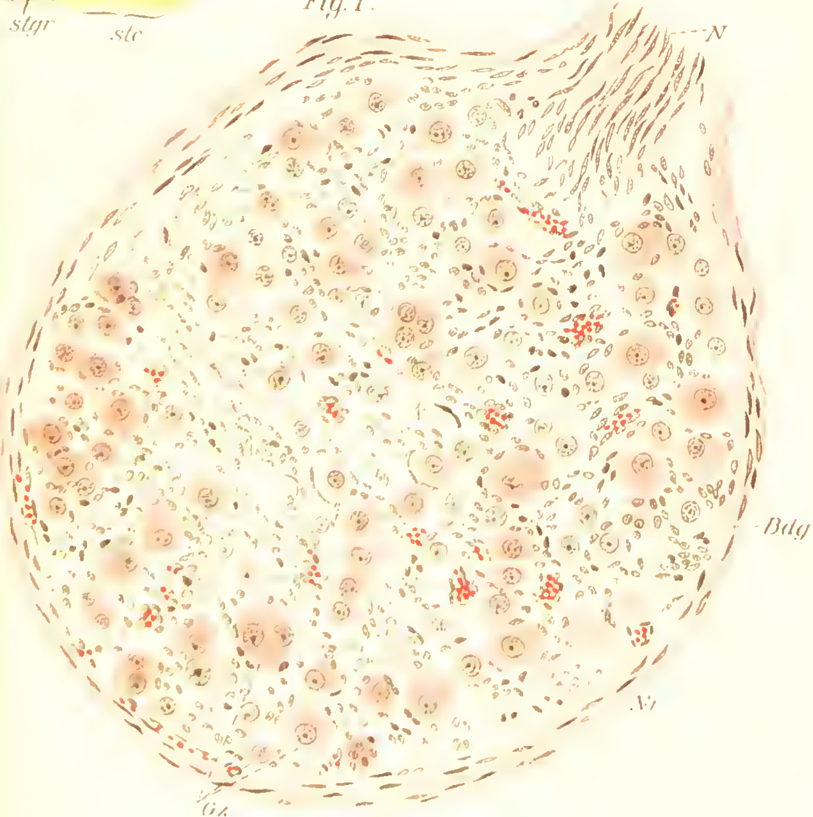


Fig. 1.



granular and molecular zones at the level at which the dendrites of the cells of Purkinje are given off, and forms with its end branches a basket-like network around the bodies of these cells. The cortical cells found throughout the molecular layer are small cells with short dendrites; it is thought that their neuraxes have no relation with the cell-bodies of the cells of Purkinje.

The *granular layer* contains small ganglion-cells, which have large nuclei and small cell-bodies, differing from those of other ganglion-cells. They have very little similarity to other nerve-cells, but resemble the cells of the inner granular layer of the retina. They are multipolar, with few dendrites with peculiar claw-like endings. Their neuraxes pass vertically up into the molecular layer, where they undergo a T-shaped division and probably without branching run parallel to the surface of the cerebellum, passing through the dendrites of the cells of Purkinje. Besides the ordinary small granular cells, there are also large granular cells, which belong to the nerve-cells of type II of Golgi (see page 72). Neither the neuraxes of the small cells of the molecular layer nor those of the granular layer pass over into medullated nerve-fibers. In Golgi preparations the *neuroglia* of the cerebellum presents the following structure and distribution: Long-rayed astrocytes are found mainly in the white matter, short-rayed cells in the granular zone, modified short-rayed cells in the molecular layer, the cell-bodies being found in the region of the bodies of the cells of Purkinje and the processes radiating out toward the surface of the cortex.

While the cerebellar cortex shows throughout exactly the same structure, the *cerebral cortex* has a somewhat different structure in the different regions; its structure is not so complicated as that of the cerebellum, and above all no distinct layers, visible macroscopically, can be recognized.

In general, the cerebral cortex is characterized by the presence of one variety of nerve-cell, the *pyramidal cell*.

The other ganglion-cells occurring in the cerebral cortex may be regarded as modified pyramidal cells, so that the cerebral cortex, in contrast to the cerebellar cortex, contains but *one* essentially characteristic variety of cell.

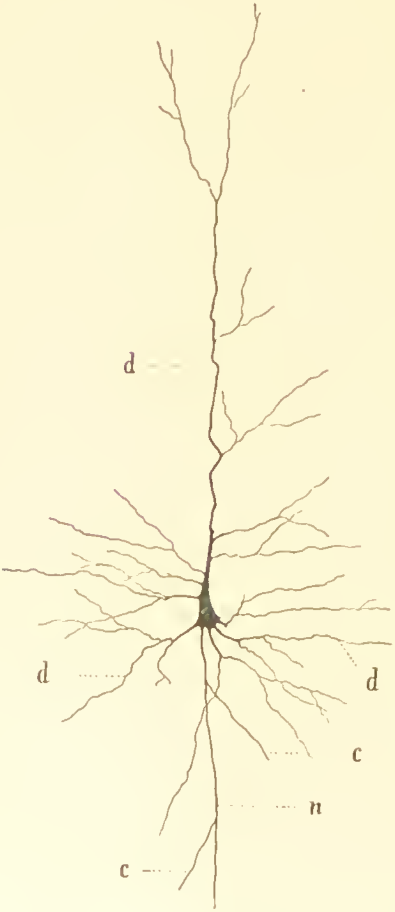


Fig. 33.—A pyramidal cell of the cerebral cortex of man. × 90. *c*, Collaterals; *d*, dendrites; *n*, neuraxis.

The following layers are recognized in the cerebral cortex: An outer molecular layer containing numerous neuroglia elements, the layer of small pyramidal cells, the layer of large pyramidal cells, the layer of polymorphous cells; then follows the white matter, consisting mainly of medullated nerve-fibers.

The pyramidal cells have three main dendrites, which arise from the angles of the pyramidal cell-bodies. The cell-body stands with its long axis vertical to the surface of the convolutions. The main dendrite, which is at the same time the longest, runs directly toward the surface of the cortex. The three dendrites branch freely, but do not extend so far as those of the cells of Purkinje. The neuraxis of the pyramidal cell arises from its base, giving off collaterals, and continues as a medullated nerve-fiber into the white matter. The pyramidal cells occur in typical form in the middle layer of the cerebral cortex and the largest (up to 30 μ in size) in the deeper portions of the middle layer. Certain very large pyramidal cells, occurring in special regions of the cerebral cortex, are known as giant pyramidal cells. It is customary to speak of an outer layer of small pyramidal cells and a deeper layer of large pyramidal cells, but the transition of one layer into the other is gradual. In the outermost layer of the cerebral cortex, which consists largely of the dendrites of the pyramidal cells and neuroglia elements, there are only smaller cells resembling nerve-cells, which by some observers are also regarded as neuroglia cells. In the deepest layer of the cortex, below the large pyramidal cells, are found again some smaller cells, which form a transition from pyramidal cells to irregular multipolar cells. The ascending dendrite is especially poorly developed in them, or not developed at all. In addition to the nerve-cells mentioned, we find in the cerebral cortex ganglion-cells of type II (Golgi cells).

The *nerve-fibers* of the cerebral cortex radiate from the medullary substance into the cortex. They are made up of the neuraxes of the small and large pyramidal cells, fibers of unknown origin which radiate into the cortex and end there, and the tangential fibers of the cerebral cortex. The latter run as very fine fibers, partly close under the surface of the cerebral convolution in the external molecular layer, partly at different levels parallel to the surface, and in certain regions as a prominent layer half way between the surface and the white substance, forming the stripes of Vic d'Azyr or of Gennari. (See Plate 18.)

The neurogliar elements of the cerebral cortex present no peculiarities; in Golgi preparations the white substance contains especially long-rayed astrocytes, and the gray substance contains short-rayed cells.

As in the spinal cord, the *blood-vessels* of the brain form capillary networks principally in the gray substance. The *choroid plexuses* of the brain ventricles contain many blood-vessels, which are overlaid by cubical epithelial cells.

PLATE 18.—CEREBRAL CORTEX; TACTILE CORPUSCLE.

FIG. 1.—**Portion of a Section of the Human Cerebral Cortex Vertical to the Surface.** × 20.

The figure shows the cross-section of the entire gray substance and of the adjacent portion of the medullary substance. The medullated nerve-fibers are stained.

Technic: Müller's fluid. Weigert's stain for medullary sheaths.

Reference letters: *atf*, External tangential fibers; *intf*, inner tangential fibers; *M*, medullary substance (white matter); *R*, cortex (gray matter).

FIG. 2.—**Longitudinal Section of a Papilla of the Corium with Tactile Corpuscle.** × 340.

Preparation from Prof. Kallius, Göttingen.

The figure shows a papilla of the corium, without the epidermis, with a tactile corpuscle. The entering nerve with its extensions in the corpuscle is stained blue.

Technic: Intra-vitam methylene-blue stain. Alum-carmin.

Reference letters: *nf*, Nerve-fiber.

The latter are the *unchanged* remains of the original epithelium of the neural canal, since in these places it develops neither into nerve substance nor into neuroglia. The cells usually contain yellow pigment (see page 107). The *lymph-vessels* of the central nervous system are mostly perivascular and begin with pericellular spaces. Larger lymph-vessels lie under the arachnoid and dura, constituting the subarachnoid and subdural spaces.

The *membranes* of the central nervous system are of connective tissue, the dura mater consisting of formed connective tissue, the arachnoid and pia of looser connective tissue, containing many blood-vessels.

The *hypophysis* is developed from two sources, the floor of the thalamencephalon and the oral ectoderm. The posterior or cerebral lobe is continuous with the infundibulum, but contains very little or no nerve tissue; the anterior, the larger lobe, developed from the oral ectoderm, is

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Fig. 31.—Portion of a vertical section of human cerebral cortex, treated by the Golgi method. × 70. The figure shows the arrangement of the different cells of the cerebral cortex. *gP*, Layer of large pyramidal cells; *kP*, layer of small pyramidal cells; *pZ*, layer of polymorphous cells.

Tab. 18.

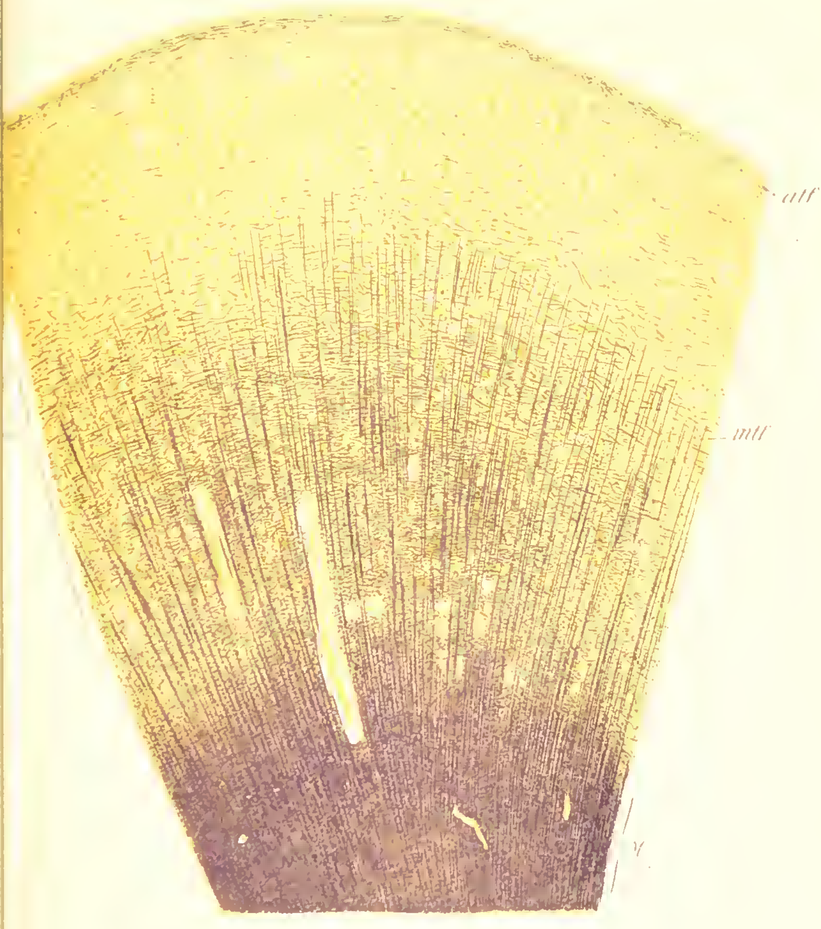

Fig. 1

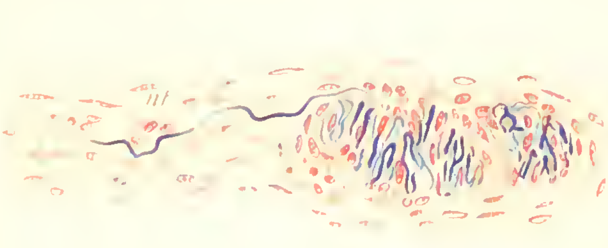

Fig. 2.

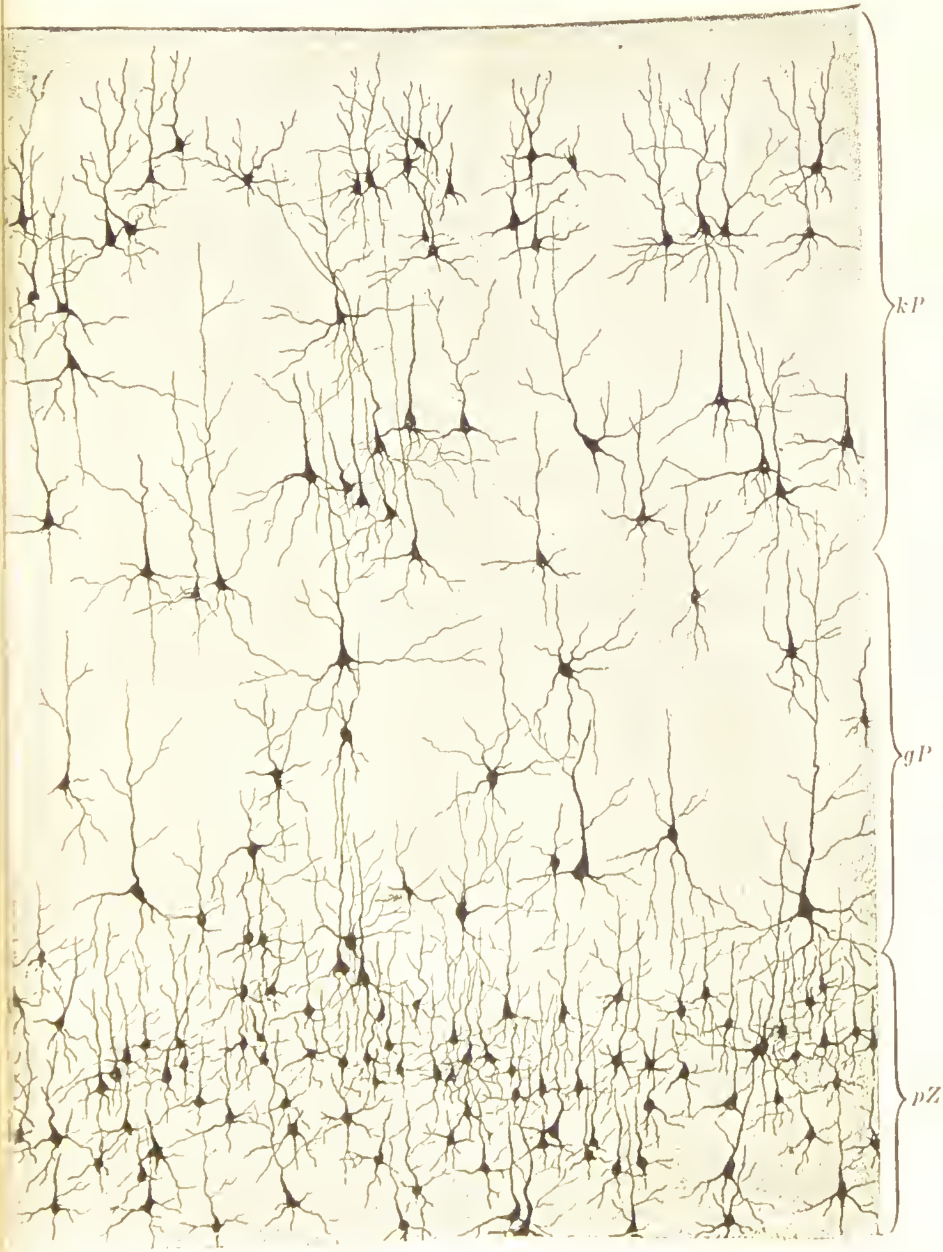

Fig. 34.

made up of anastomosing trabeculæ or columns of cells, of which are recognized two varieties, the chief and the chromophile cells. Now and then certain of the trabeculæ present a lumen and appear to have an internal secretion. A capillary network is found between the trabeculæ of cells, accompanied by a small amount of fibrous connective tissue.

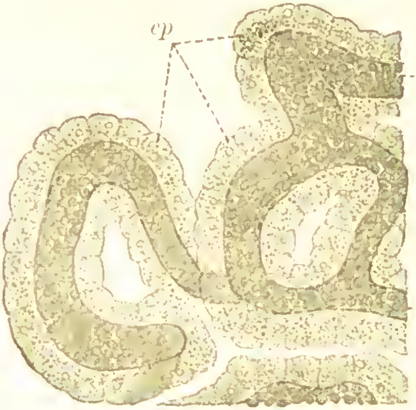

Fig. 35.—Portion of choroid plexus from the lateral ventricle of a human brain, observed in the fresh condition. × 250. *c*, Capillaries; *cp*, epithelium.

The *epiphysis* or pineal gland is developed from the roof of the thalamencephalon. In the higher vertebrates it is a rudimentary structure. In it are found closed alveoli, lined by a stratified epithelium, often containing small concretions known as brain sand. It further contains neuroglia tissue.

2. THE PERIPHERAL NERVOUS SYSTEM.

(*a*) The peripheral **nerves.** Every peripheral nerve consists of a varying number of *nerve bundles* or nerve funiculi; these are cylindric cords consisting of groups of medullated nerve-fibers. The nerve bundles vary greatly in size, even in the same cross-section, and each one is surrounded by a firm sheath of connective tissue with elastic fibers, the *perineurium*. From the perineurium processes pass into the nerve bundle, known as *endoneurium;* these form an irregular network and generally inclose irregularly shaped secondary bundles. Each single nerve-fiber receives from the endoneurium a delicate sheath, the so-called

PLATE 19.—PERIPHERAL NERVES.

Fig. 1.—**Transverse Section of a Human Peripheral Nerve.** × 27.

The preparation was taken from a man who had been executed. The figure gives a picture of a peripheral nerve with its connective-tissue sheaths.

Technic: Müller's fluid. Picric-acid acid-fuchsin according to Van Gieson.

Reference letters: *bg*, Blood-vessels; *en*, endoneurium; *epn*, epineurium; *pn*, perineurium.

Fig. 2.—**Portion of Fig. 1, under Higher Magnification.** × 280.

The figure shows cross-sections of fibers of very different sizes (axis cylinder red and medullary substance yellow) within the endoneurium.

Reference letters: *a*, Axis cylinder; *en*, endoneurium; *ma*, medullary sheath.

Henle's fibrillar sheath. In the nerve bundle nearly all the fibers run in the direction of the long axis of the nerve, with the exception of places where branches are given off or communications take place between the bundles. Each larger nerve consists of a collection of nerve bundles, which are held together by loose connective tissue, often containing fat-cells; this surrounds the entire nerve and is called the *epineurium.* The sympathetic nerves have numerous non-medullated nerve-fibers in addition to the varying number of fine medullated fibers and a few large medullated fibers.

(*b*) The peripheral **ganglia**; cerebro-spinal and sympathetic ganglia. These occur in all gradations of size—the scattered ganglion-cells of the tongue, adrenal, etc., the small ganglia of the intestine, and the large complexus of the spinal and large sympathetic ganglia.

The *spinal ganglia* and the sensory cranial ganglia have mainly the *large, spherical,* unipolar *ganglion-cells* (see page 73). Each of these is surrounded by a nucleated connective-tissue capsule or sheath, which is closely applied to the cell-body (see Plate 7, Figs. 3–5). The dorsal sensory spinal roots, in the course of which these cells are interpolated, are made up of the two processes resulting

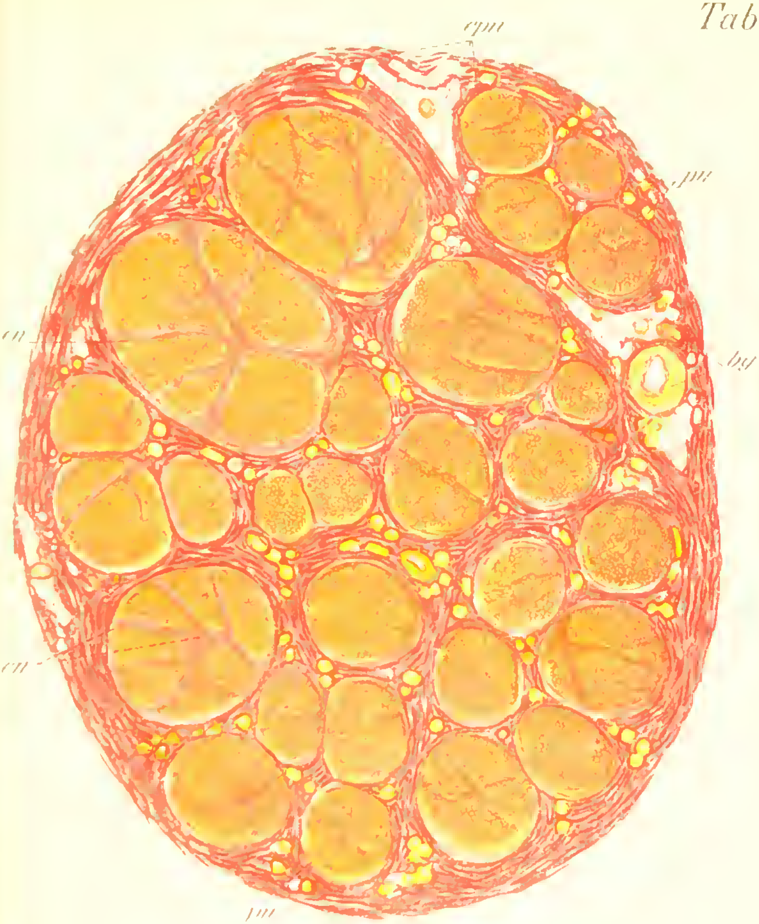

Fig. 1.

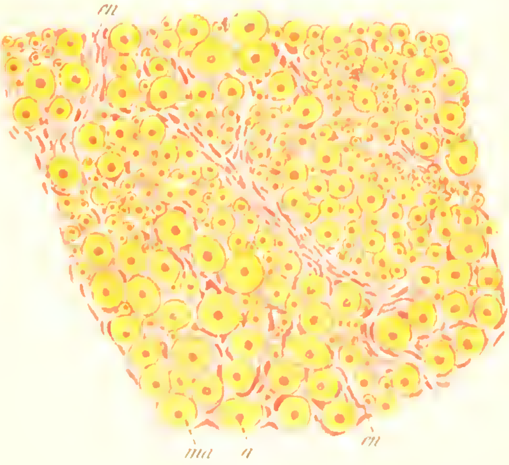

Fig. 2.

from the division of the single process of the cells; one of these two processes passes to the periphery and the other toward the center.

The number of spinal ganglion-cells of the spinal ganglia is, however, much greater than that of the sensory root-fibers which enter. There is in the spinal ganglia a *second form of cells*, the neuraxes of which do not go into the dorsal roots, but branch many times soon after their exit from the ganglion-cells and end in extracapsular and intracapsular terminal branches which surround the cell-bodies of the unipolar cells. Sympathetic nerve-fibers forming plexuses are also found in the ganglia.

The *sympathetic ganglia* contain unipolar, bipolar, and multipolar cells, their elements being often polynuclear. The cells of the sympathetic ganglia, like those of the spinal ganglia, have a nucleated connective-tissue capsule. The processes, dendrites as well as neuraxes, pierce this. Most of the cells are motor; their neuraxes pass into the non-medullated nerve-fibers and innervate non-striped muscle and heart muscle; others are secretory, innervating gland-cells. Another form of cell in the sympathetic ganglia has very long dendrites, which run into the neighboring ganglia; the neuraxis, after proceeding for some distance on its course, receives a thin medullary sheath. These cells are thought to be sensory sympathetic cells. The sympathetic ganglia contain also medullated cerebrospinal fibers, which terminate in intracapsular pericellular baskets, and cerebro-spinal sensory fibers, which merely pass through the ganglia.

(*c*) The **nerve-endings.** The nerve-endings may be separated into *motor* and *sensory* nerve-endings. The former are found on the terminal branches of medullated motor nerve-fibers of transversely striated muscle. On reaching the muscle, medullated motor nerve-fibers rapidly divide into a varying number of small medullated nerve-fibers. Each one of these terminal medullated branches, on reaching the muscle-fiber which it innervates, loses its

PLATE 20.—PERIPHERAL GANGLIA.

FIG. 1.—**Transverse Section of the Superior Cervical Ganglion of the Human Sympathetic Nervous System.** × 26.

The preparation was taken from a man who had been executed.

The figure shows a picture of a sympathetic ganglion with numerous typical sympathetic cells, and many darkly stained, but generally very fine medullated nerve-fibers. (The numerous non-medullated nerve-fibers are not visible on account of the low magnification. Compare Fig. 2, Plate 17.)

Technic: Müller's fluid, staining of medullary sheaths according to the Weigert-Pal method. Alum-carmin.

Reference letters: *cf*, Fibrous capsule; *gz*, ganglion-cells; *mn*, medullated nerve-fibers.

FIG. 2.—**Transverse Section through a Spinal Ganglion of Man.** × 12.

The preparation was made from tissue fixed two and one-half hours after death.

The figure shows the two roots of the spinal cord surrounded by the dura mater; the motor fibers are divided into two large bundles; those of the sensory root are scattered through the ganglion.

Technic as in Fig. 1.

Reference letters: *dm*, Dura mater; *F*, fat tissue; *frs*, fibers from the sensory roots; *Gz*, ganglion-cells; *rm*, motor root.

medullary sheath, while its neurilemma becomes continuous with the sarcolemma of the muscle-fiber. The neuraxis passes under the sarcolemma and ends after further division in a mass of granular sarcoplasm known as the sole plate or end-disc. In this sole plate are found numerous nuclei, probably derived from the nuclei of the muscle-fiber. Especially large motor end-plates and motor endings are found in the reptilia.

The *sensory* nerve-endings are divided into two main groups: (1) The *simple endings* or free sensory endings; (2) the special *terminal apparatus* or *terminal corpuscles*, known as the encapsulated sensory nerve-endings. Between

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Fig. 36.—Branching of a nerve in an abdominal muscle of a mouse, prepared by gold impregnation. × 120. The figure shows the motor end-plates on the muscle-fibers under low magnification. *m*, Muscle-fiber; *me*, motor end-plates; *n*, nerve.

Fig. 37.—Two motor end-plates from a muscle of a lizard. × 250. The figure shows a smaller and a larger motor end-plate, prepared by gold impregnation. *n*, Entering nerve-fibers; *sch*, end-plate, with the terminal distribution of the nerve.

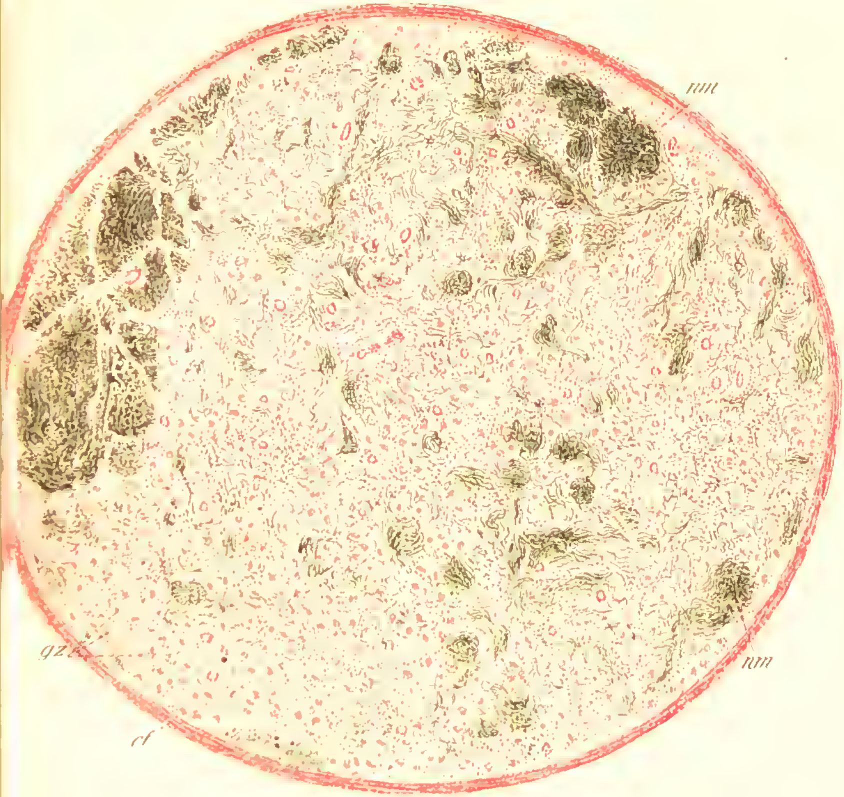
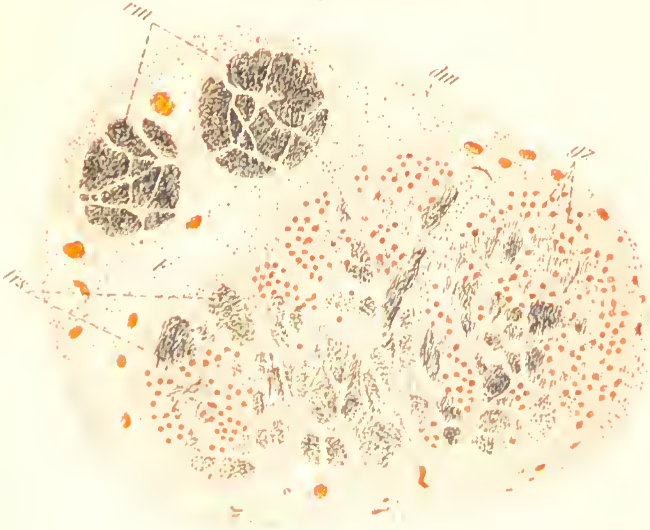


Fig. 1.



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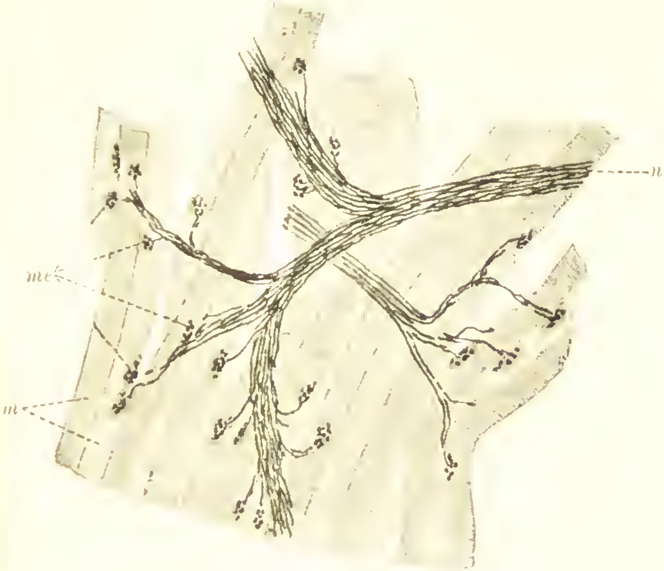

Fig. 36.

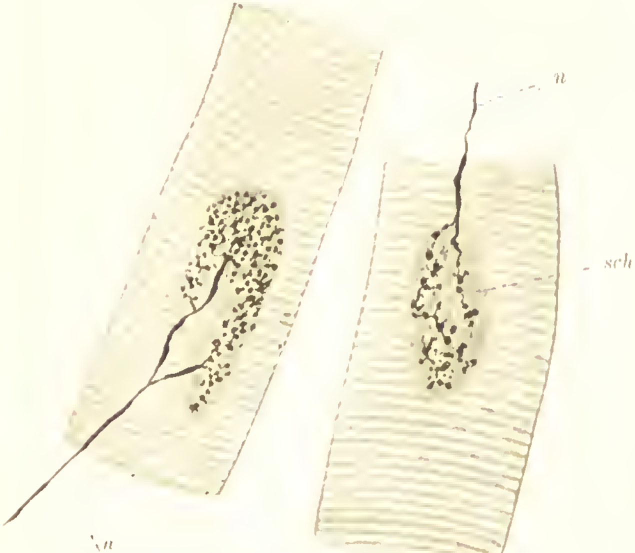

Fig. 37.

the two are the sensory nerve-endings in the neuromuscular and neurotendinous nerve end-organs, which occupy an intermediate position, in that they show free sensory endings on muscle-fibers and tendon fasciculi, the whole being surrounded by a thin connective-tissue capsule.

The *free nerve-endings* represent simple terminal branches of the sensory nerves, which either end in a point or show a terminal nodular enlargement; these occur especially in *epithelia*, but also in fibrous connective tissue. The occurrence of a terminal *network* is doubtful. How widely distributed the simple free endings are is at present somewhat difficult to state. The nerve-endings in the ducts of all glands are probably of this variety. In many sense organs also (organs of hearing, taste, etc.) the nerves spread out in the form of somewhat modified, simple endings.

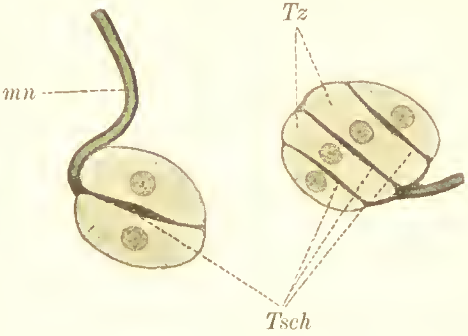

Fig. 38.—Transverse section of two Grandry's corpuscles from the tongue of a duck. × 450. One of the corpuscles shows two and the other four tactile cells. *mn*, Medullated nerve-fibers, entering the corpuscle; *Tsch*, tactile discs; *Tz*, tactile cells.

The so-called *tactile cells* of the skin form a transition between the simple free endings in the epithelium and the special terminal corpuscles or encapsulated endings found without exception in the connective tissue. These lie in the epidermis and consist of somewhat enlarged clear epithelial cells to which a flat, saucer-like enlargement of the nerve-fiber is applied, forming the so-called *tactile meniscus*.

In true terminal corpuscles the free end of the nerve-fiber may be found in a club-shaped mass of a granular substance, in some instances nucleated, which by some

Fig. 39.—Portion of a vertical section of a rabbit's cornea, treated by the gold chlorid method. × 375. The figure shows the arrangement of the nerves in and under the epithelium of the cornea. *ep*, Epithelium; *ien*, intra-epithelial nerves; *lea*, lamina elastica anterior (Bowman); *n*, larger nerve branches; *sen*, subepithelial nerves; *stp*, stratum proprium corneae.

Fig. 40.—Vater-Pacinian corpuscle from the mesentery of the cat, fixed in a platinum chlorid-osmic acid solution. × 45. The figure gives a general view of the corpuscle and not a cross-section. *a*, Axis cylinder in the core; *ik*, core; *mn*, medullated nerve-fibers entering the corpuscle.

Fig. 41.—Longitudinal section of a Herbst corpuscle from a duck's tongue. × 380. *h*, Inner concentric sheaths; k_1, nuclei of core; k_2, nuclei of outer sheaths; *n*, nerve-fiber (axis cylinder) in the corpuscle; *mn*, medullated nerve-fiber, penetrating the outer sheath.

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observers is regarded as neuroplasm, and which is surrounded by a connective-tissue sheath, as in the encapsulated lamellar corpuscles or end-bulbs; or the nerve-fibers at their ends may show plate-like terminations, which are found between peculiar epithelioid connective-tissue cells (according to some authors epithelial cells), as in Grandry's corpuscles. In man, only the former are found.

Grandry's corpuscles are especially frequent in the bill and tongue of water birds. They consist of two or more large, flattened, spherical or hemispherical protoplasmic cells. Between the cells is found the terminal distribution of a medullated nerve-fiber in the form of a disc, like expansions of the axis cylinders. The number of tactile discs is therefore always less than the number of the cells. Grandry's corpuscles possessing only two cells are found; corpuscles having four and even more cells are, however, also met with.

The largest and best developed lamellar corpuscles of the human body are the *Vater-Pacinian corpuscles*. They are found principally in the subcutaneous fat tissue of the vola manus, of the finger, and of the sole of the foot; also on and in tendons and fibrous sheaths of muscles, in the periosteum, in the retroperitoneal region and mesentery, and in the connective tissue surrounding large arteries and veins. They are especially large and numerous in

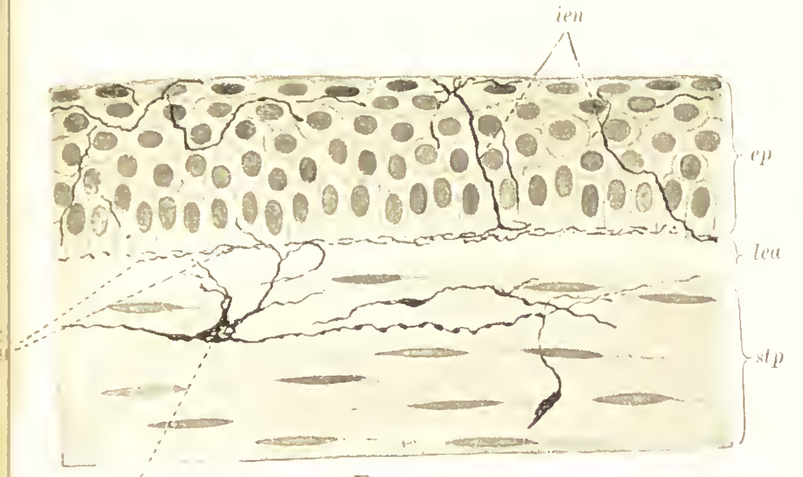

Fig. 39.

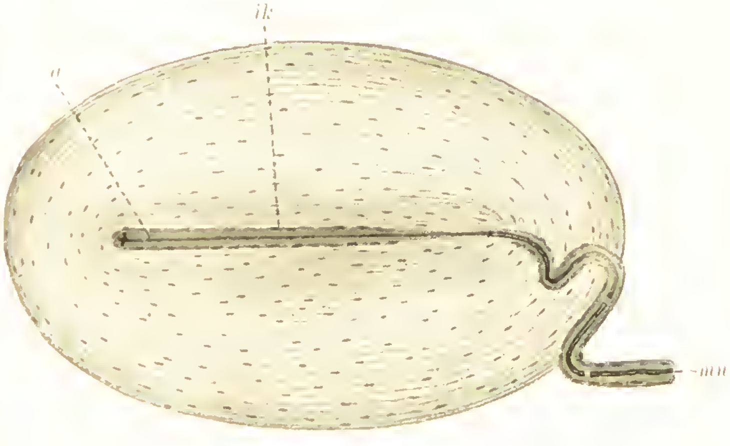

Fig. 40.

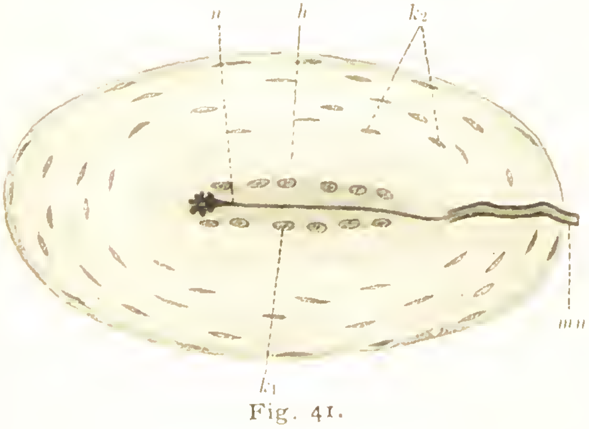

Fig. 41.

the mesentery and mesorectum of the cat. They are visible macroscopically, being two and even four millimeters in diameter. The medullated nerve-fiber enters the corpuscles and becomes non-medullated at the boundary of the inner and outer layers of the corpuscle. The axis cylinder then runs within a club-shaped, granular, protoplasmic mass, the so-called inner core, through the axis of the corpuscle, to end in one or several knob-like enlargements. In its course through the core the axis cylinder gives off numerous short side branches. The core, with the central axis cylinder, is surrounded by concentric connective-tissue sheaths or capsules, which are rich in elastic fibers and have rows of nuclei between them. In the neighborhood of the core the lamellæ are thin, but toward the periphery they are considerably thicker.

The *Herbst corpuscles* of birds are very similar to the Vater-Pacinian corpuscles; they are, however, much smaller and show at the outer surface of the core a single or double row of nuclei, outside of which are seen several slightly wavy, non-nucleated lamellæ resembling elastic tissue, and external to these a few not very well developed connective-tissue sheaths with few nuclei.

The spherical end-bulbs of the conjunctiva, Meissner's corpuscles, and the genital corpuscles and similar nerve-endings form a distinct group, possessing a relatively thin connective-tissue capsule surrounding a semi-fluid granular substance which we may designate as the core. One or several medullated nerve-fibers enter each corpuscle, and, after losing their medullary sheaths, undergo repeated division, forming numerous varicose branches, which are variously interwoven and intertwined. In Plate 18, Fig. 2, is shown a Meissner's corpuscle, seen in longitudinal section.

The nerves of the neuromuscular and neurotendinous spindles branch several times before reaching their respective spindles and, while still medullated, pass through the capsule and axial sheath. The medullary sheath is lost within the axial sheath. In the former, the naked axis cylinders end partly in rings or spirals and partly in branched, flower-like endings, which surround the intrafusal muscle-fibers in the equatorial region of the spindle. In the latter, the naked axis cylinders, after branching several times, run along the intrafusal tendon fasciculi, give off numerous side branches, which end in irregular discs, which partly enclamp the tendon fasciculi.

IV. BLOOD AND LYMPH VASCULAR SYSTEM.

Under the blood and lymph vascular system we shall consider the heart and blood-vessels, the lymph-vessels, lymph-glands and smaller lymphatic structures, and the spleen and thymus.

The **heart** is an enlarged and differentially developed portion of the blood vascular system. In it are distinguished the following three layers: The inner, the endocardium; the middle, the myocardium; and the external, epicardium (see Plate 16, Fig. 2).

The *endocardium* consists of a layer of endothelial cells (see page 42) beneath which is found a relatively thick layer of fibro-elastic tissue, the elastic tissue being here and there arranged in the form of elastic plates. Smooth muscle-fibers are now and then found in the endocardium. The *myocardium* consists of transversely striated heart muscle, which occurs in several layers of complicated arrangement, and in general takes its origin from the annuli fibrosi in the region of the atrio-ventricular borders.

Perimysial sheaths of connective tissue envelop the fasciculi of heart muscle, the finest strands of which surround the single cross-striped fibers. This connective tissue serves as the carrier of the nerves and blood-vessels of the heart muscle, and in all essential points conducts itself just as in ordinary cross-striped skeletal muscle (see Plate 6, Fig. 3).

The *epicardium,* the visceral layer of the serous pericardium, consists of connective tissue, beneath which occurs the subpericardial adipose tissue. It is covered by a single layer of flattened mesothelial cells. The heart receives its nerve-supply from both the sympathetic and cerebrospinal nervous system. The sensory endings are found in the epicardium and pericardium. The heart muscle receives its innervation from sympathetic neurones, the cell-bodies of the majority of which are situated in ganglia found in the heart; others are in ganglia of the cervical sympathetic. White rami, branches of the upper dorsal nerves, end in these ganglia.

Like the interior of the heart, all the **blood-vessels** are lined by a single layer of flattened endothelial cells. The smallest vessels, the *capillaries,* consist of an endothelial tube; rarely, in the largest capillaries, some connective-tissue cells of the neighborhood are joined to the wall, forming an adventitia capillaris.

In the capillaries of certain tissues, the cell boundaries disappear, forming a syncitial endothelial tube, as for instance in the glomerular capillaries of the human kidney. The form of the endothelial cells is elongated, often very long, especially so in many veins; there are no essential and characteristic differences in the structure and shape of endothelial cells in the different portions of the vascular system. The cell boundaries are best brought out by treatment with silver nitrate, and consist of serrated lines. Outside of the endothelial tube the arteries and veins possess a number of sheaths or membranes, which consist of connective tissue, elastic tissue, and smooth muscle. These three kinds of tissue are distributed in the vessel walls in a manner varying not only in veins and arteries, but also according to the size and caliber of the vessels concerned, and in veins according to other considerations.

Although, according to more recent investigations, the division of the vessel wall into three layers—namely, the tunica intima, media, and adventitia—cannot be strictly maintained, and is even to a certain extent irrational, we retain the old classification on account of convenience of description.

In the structure of **arteries** we must distinguish large arteries, as the aorta and its direct branches, median arteries, from the brachial to the digital, and small arteries, from branches of the digital to the precapillary arteries. It is mainly in the *media*, the structure of which is dependent on the caliber of the arteries, that the structural differences are manifested, since in the media of the larger vessels the elastic elements predominate over the muscular, while in that of the smaller arteries the elastic elements are almost entirely wanting.

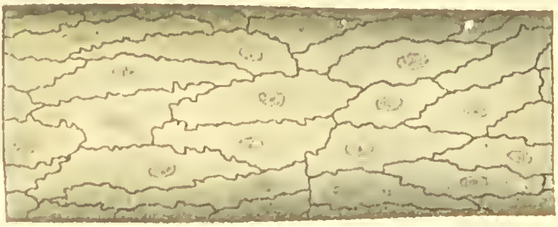

Fig 42.—Portion of small artery from the bladder of a frog, treated with silver nitrate solution. × 375. The figure shows the endothelial tube. Besides the nuclei, we see the cell boundaries, blackened by the silver reaction.

The media of the *smallest* precapillary arteries consists only of circularly arranged smooth muscle-fibers in from one to three layers; in arteries slightly larger, but still of very small caliber, as for instance in branches of the digital arteries, fine elastic fibers are found in the media. The larger the artery, the greater is the relative number of elastic elements; however, the number of elastic elements does not in all arteries increase in proportion to the decrease in the muscular tissue. The elastic elements of the media of median arteries are quite uniformly distributed in the form of finer and coarser fibers between the muscle-fibers of the media, and like these are circularly arranged. In the *larger* of the median arteries, as the carotid, subclavian, iliac, the elastic tissue begins to be more prominent in the media, and at the same time *elastic plates* or fenestrated membranes occur in place of the elastic fibers; these also are for the most part arranged circularly. In the aorta the musculature becomes unimportant in contrast to the elastic plates, which occur in many layers and make up almost the entire thickness of the media.

The *intima* shows less marked changes in relation to the caliber of the arteries. At the border of intima and media, all arteries of every caliber present wavy, elastic plates, very distinct and marked in the smallest arteries, the so-called elastic intima. In the aorta the elastic intima is no longer conspicuous, because the entire media is filled with similar elastic plates. In the smallest arteries this alone represents the intima, the endothelium resting directly upon it. In the larger arteries, in the small and especially in the medium-sized arteries, there is found a layer of subendothelial connective tissue, consisting of fibrous and elastic connective tissue and connective-tissue cells.

The *tunica externa* or *adventitia* of the arteries is formed of loose connective tissue with elastic fibers and rarely also smooth muscle. The smooth muscle cells are always lacking in the large and small arteries, occurring occasionally in some median arteries, but then only in the form of sparsely distributed longitudinal bundles. In general the adventitia of the arteries of the human being is free from muscle. In certain mammals it is generally present; in the aorta of cattle, for instance, it occurs as compact, longitudinally arranged bundles. The adventitia is in general thicker, the greater the caliber of the artery. The elastic elements appear in the main in the form of longitudinal fibers, which are few and fine in the smaller arteries, more abundant and larger in the medium-sized arteries, in which they occasionally form an elastica externa, and are especially well developed in the largest arteries, like the aorta and its main branches. The adventitia of the latter and

PLATE 21.—ARTERIES.

FIG. 1.—**Part of a Cross-section of a Human Thoracic Aorta.** × 40.

The preparation was taken from one who had been executed.

The figure shows in the main the elastic elements of the aortic wall. The musculature lying in the spaces between the elastic plates of the media is not stained.

Technic: Müller's fluid. Orcein.

Reference letters: *J*, Tunica intima; *M*, tunica media, with many elastic plates; *A*, tunica externa adventitia, with vasa vasorum.

FIG. 2.—**Part of a Cross-section of the Human Arteria Radialis.** × 170.

The preparation was taken from tissues fixed two and one-half hours after death.

The figure shows the lamination of the artery wall. The elastic layers are stained dark red with orcein; the cell nuclei, especially those of the circular muscle of the media and those of the endothelial cells, blue with hematoxylin.

Technic: Zenker's solution. Orcein-hematoxylin.

Reference letters: *a*, Small artery of the adventitia; *A*, tunica adventitia; *eli*, lamina elastica interna; *J*, tunica intima with the endothelium; *M*, tunica media, forming toward the adventitia a kind of elastica externa; *vv*, vasa vasorum.

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of its main branches contains a well-developed network of fiber strands of longitudinal course.

Only a few arteries, like the arteries of the brain, the inner elastic elements of which are strongly and the outer weakly developed, vary from this type.

The **veins** are much more difficult to classify than the arteries, since the thickness and structure of their walls depend, not alone on the caliber, but also on other factors, such as the position of the vessels—for example the veins found in the extremities, in the skin, in the abdomen, or in the head. The veins of the abdomen and of the head possess very little muscle, while the veins of the skin contain a relatively large amount of muscle, so that their walls are scarcely thinner than those of the arteries of the same caliber—for instance the arteries which accompany them. In other places the veins have much thinner walls than the accompanying arteries. It may therefore be seen that veins of the same caliber may show very different structure and very different thickness of walls.

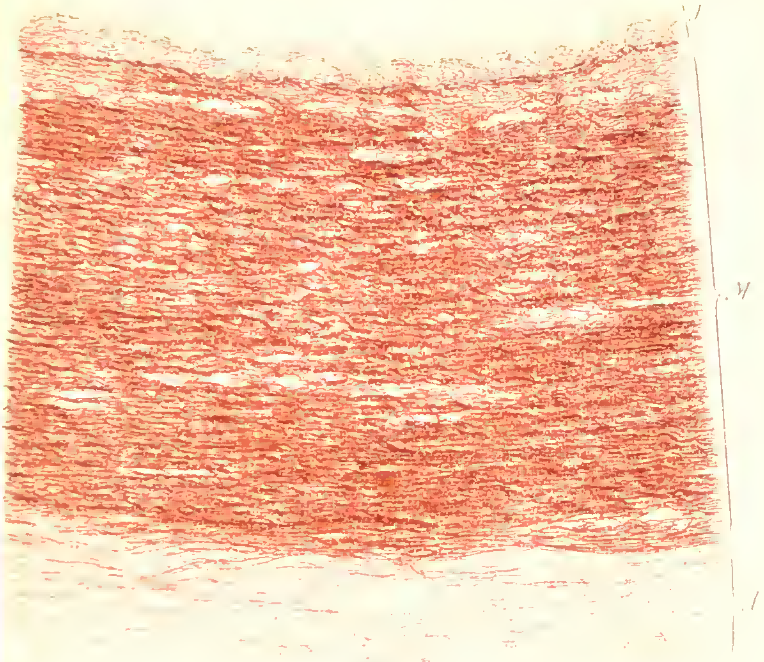

Fig. 1.

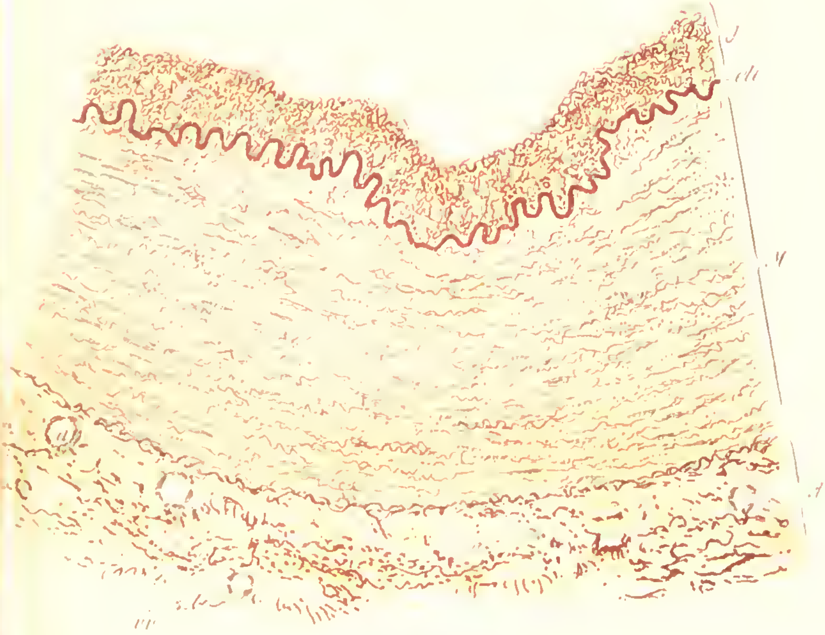

Fig. 2.

In general the veins contain fewer elastic elements than the arteries, and the media is relatively poor in muscle even in veins which contain much muscle, while in other veins it is scarcely demonstrable; on the other hand, the adventitia of the skin veins especially contains a considerable quantity of muscle.

The *intima* of the veins consists mostly of fibrous connective tissue and contains only a few elastic fibers. It also forms the *valves* of the veins. On the borders of the media, or even within the intima, the elastic elements of the intima collect into an elastica interna, which, however, is not so well defined as in the arteries, nor has it the wavy course, nor does it occur in all veins.

The *media* of veins, in so far as it may be differentiated, contains the same elements as that of arteries, consisting of circularly arranged muscle-fibers and elastic fibers or networks; but it also contains some connective tissue, so that the muscle appears less compact. Only the media of the muscular veins, however, is constructed in this way; in others, it is either very much reduced or entirely lacking, as in the veins of the abdomen and head. The *adventitia* of most veins contains *longitudinal muscle.* In muscular veins this lies in large, compact bundles between networks of longitudinal elastic fibers.

The blood-vessels, at least the large and median arteries and veins, but never the small ones and capillaries, contain blood-vessels in their own walls, known as vasa vasorum. These are to be found mostly in the adventitia, but in the very large vessels, as the aorta, we find that capillaries extend also into the external layers of the media, while the externa contains the small nutrient arteries and veins.

The *nerve-fibers* of the blood-vessels are in part nonmedullated sympathetic fibers for the muscle coats; others are medullated, sensory fibers, which are in part distributed in the intima, the majority, however, terminating in the externa.

PLATE 22.—BLOOD-VESSELS.[1]

FIG. 1.—**Cross-section of a Muscular Vein of the Pampiniform Plexus.** × 50.

The preparation was taken from a man who had been executed.

The figure shows a cross-section of a vein with longitudinal muscle in the adventitia. The elastic tissue is stained dark violet.

Technic: Zenker's solution. Weigert's elastic tissue stain. Alum-carmin.

Reference letters: *A*, Tunica externa or adventitia; *J*, tunica intima; *M*, tunica media with circular musculature; *lm*, longitudinal muscle of the adventitia; *vv*, vasa vasorum, among them a very small artery of the caliber of that in Fig. 4.

FIG. 2.—**Transverse Section of a Larger Branch of the Internal Spermatic Artery from the Spermatic Cord.** × 80.

The preparation was taken from a man who had been executed.

The figure shows a typical picture of a small median artery. The media contains smooth muscle and very few elastic fibers.

Technic as in Fig. 1.

Reference letters: *A*, Tunica adventitia; *ei*, lamina elastica interna; *en*, endothelium; *J*, intima; *M*, media.

FIG. 3.—**Transverse Section of a Small Branch of the Internal Spermatic Artery from the Spermatic Cord.** × 220.

The figure shows the cross-section of a small artery. The intima is reduced to the endothelium and the elastica interna; the media consists almost entirely of muscle; there is a distinct elastica externa.

Technic as in Figs. 1 and 2.

Reference letters as in Figs. 1 and 2; *ee*, lamina elastica externa.

FIG. 4.—**Cross-section of a Very Small Artery (Precapillary) from the Corium.**

The figure shows the picture of a very small artery. The media consists of only two layers of muscle-fibers.

Technic and lettering as in Figs. 1–3.

The *lymph-vessels* are in all essentials like the blood-vessels in structure, except that even the largest have only very thin muscular walls. The lymph capillaries probably connect with spaces in the tissue in such a way that the latter represent the radicles of the lymph-vessels, as for instance the pericellular spaces.

Lymphoid tissue may be divided into two classes, namely: (1) True lymph-glands, situated in the deeper connective tissue; (2) lymph nodules or follicles, which

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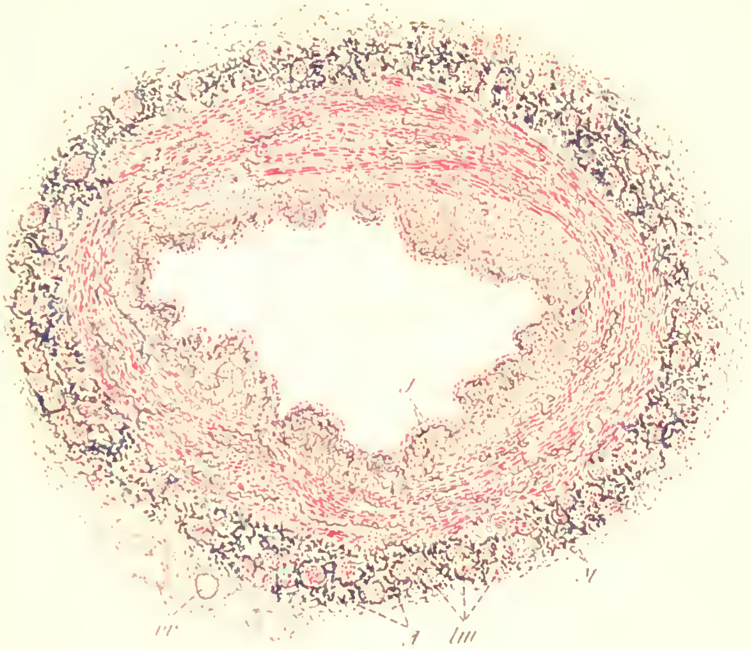
[1] In the reproduction the red-stained muscle nuclei are represented too large, especially in Fig. 1.

Tab. 22.



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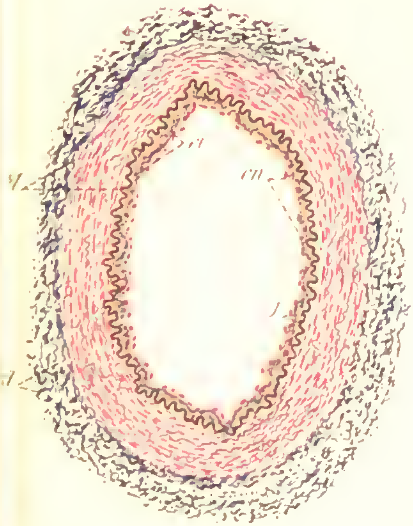

Fig. 2.

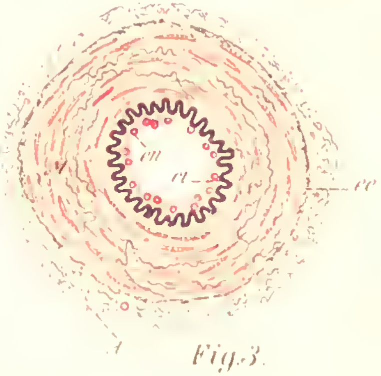

Fig. 3.

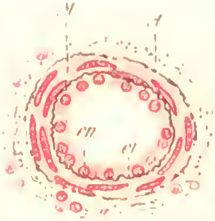

Fig. 4.

are situated directly under or in the mucous membranes and in intimate relation with their epithelial coverings.

The *lymph-glands* lie in the connective tissue and are generally bean- or kidney-shaped bodies of different sizes. The afferent lymph-vessels enter the gland through the convex border, while the efferent vessels leave through the hilum; through the latter the nutrient *blood-vessels* also enter. The lymph-glands are surrounded by a connective-tissue capsule which occasionally contains smooth muscle-fibers. It sends into the interior of the gland processes, known as *trabeculæ*, which branch and anastomose. In the anastomosing compartments formed by these trabeculæ there is found a reticular connective tissue which is connected with the trabeculæ (see page 43), and which forms the stroma of the gland, while the parenchyma is represented by lymph-cells (see page 53). The parenchyma is so arranged that we can distinguish in lymph-glands a medullary and a cortical substance.

The *cortical substance* of lymph-glands, situated mainly on the convex surface of the gland, contains between the trabeculæ a number of spherical bodies, the lymph-nodes or follicles, or the *secondary nodes* of lymph-glands. Their number varies according to the size of the organ. Occasionally neighboring follicles are connected.

The *follicles* of lymph-glands consist of lymph-cells (see page 57), which are densely arranged at the periphery, while in the center there is a clearer zone, the so-called *germ center*. In the latter the lymph-cells are larger and show distinct signs of proliferation by karyokinesis. Around the germ center the lymph-cells are more densely packed and are often arranged in quite regular concentric rows; the reticulum of the node is extremely fine and delicate.

Aside from the reticular connective tissue, the medullary substance of lymph-glands is composed of irregularly arranged anastomosing strands of lymph tissue, known as the *medullary cords* of lymph-glands. These originate

PLATE 23.—LYMPH-GLAND, SPLEEN.

FIG. 1.—**Transverse Section of a Human Cervical Lymph-gland.** × 18.

The preparation was taken from a man who had been executed.

The figure shows the general structure of a lymph-gland.

Technic: Sublimate. Hematoxylin-eosin.

Reference letters: *bg*, Blood-vessels; *cf*, fibrous capsule; *H*, hilus; *Kz*, germ center; *nl*, lymph-nodes; *sc*, cortical substance; *sm*, medullary substance; *tr*, trabeculæ; *vla*, afferent lymph-vessels; *vle*, efferent lymph-vessels.

FIG. 2.—**Portion of an Injected Spleen of a Rabbit.** × 28.

The preparation was taken from the material of the Institute for Comparative Anatomy, Würzburg.

The arterial trunks of the lymph-nodes (Malpighian corpuscles) are injected red, the veins and spleen sinuses blue.

Reference letters: *a*, Arteries of Malpighian corpuscle; *Mkn*, Malpighian corpuscle; *p*, spleen pulp.

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from the cortical substance, in which they are connected with the follicles, and pass through the entire medullary substance. In these there are no germ centers. Between the medullary cords are spaces, the so-called lymph sinuses, which are enlarged lymph spaces interpolated in the lymph current. The lymph sinuses are irregular and imperfectly bounded spaces, traversed by quite large trabeculæ of reticular tissue, so that they have no special wall. Similar sinuses are found between the cortical follicles and the trabeculæ and capsule. Lymph-vessels or capillaries do not penetrate the cortical follicles.

The lymph-glands are rich in *blood-vessels*, the capillaries of which are distributed in the medullary cords as well as in the cortical follicles.

Medullated and non-medullated *nerves* reach the lymph-glands; the former are no doubt sensory, although their mode of ending has not been fully determined; the non-medullated fibers are destined for the non-striated muscle in the capsule and the vessels.

The *lymph nodules* or *follicles* appear in two forms: (1) As so-called *solitary follicles* (noduli lymphatici solitarii), and (2) as *agminated follicles*. The former are widely distributed in mucous membranes, while the latter occur in

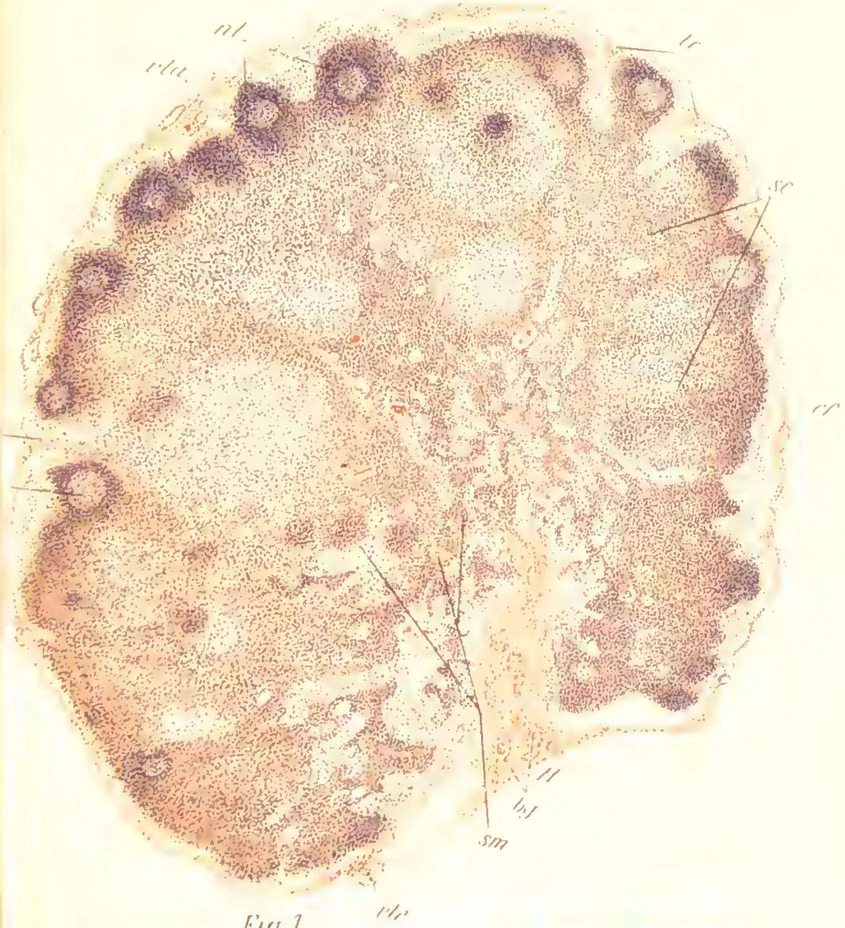

Fig 1.

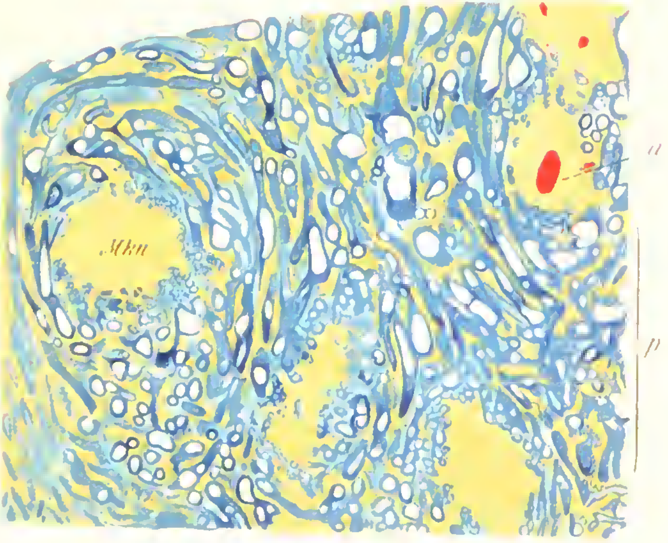

Fig 2.

Peyer's patches or the agminated glands and in the tonsils. In structure they are in the main like the cortical follicles of lymph-glands; they show no medullary cords nor lymph sinuses and also no connective-tissue capsule; they often contain, however, germ centers. The solitary follicles and agminated glands are connected with lymph-vessels through lymph spaces or imperfectly developed lymph sinuses surrounding them and are in intimate relation with the superficial epithelium (see page 139). These structures will be considered more fully in the description of the digestive tract.

It is very probable that the smallest of these structures are not permanent, but continually form and disappear. We see, therefore, all transition stages from diffuse lymphatic tissue (see page 53) and a distinctly circumscribed collection of lymph-cells to the fully developed lymph-node with germ center.

The Hemolymph Glands.—Certain lymph-glands, known as hemolymph glands, are characterized by the presence of blood sinuses and present structural peculiarities, necessitating a separate description. Hemolymph glands are numerous in the retroperitoneal region and are also found in the prevertebral region of the thorax and neck. As has been shown by Warthin, these glands may be divided into two distinct types, to which he has given the names of splenolymph and marrow-lymph glands, although transitional forms between these two types are met with, as also between lymph-glands and hemolymph glands. The splenolymph glands resemble in structure the spleen. They possess relatively thick fibro-elastic capsules containing now and then non-striated muscle tissue. Beneath the capsule is found a well-developed blood sinus, which now and then surrounds the gland tissue, and from which anastomosing sinuses penetrate the gland and separate the lymphoid tissue into irregularly shaped masses. The lymphoid tissue resembles that found in lymph-glands. The marrow-lymph glands are not so numerous as the

PLATE 24.—SPLEEN.

FIG. 1.—**Portion of Section of Human Spleen.** × 15.

The preparation was taken from one who had been executed. The figure gives a general view of the structure of spleen.

Technic: Zenker's fluid. Hematoxylin-eosin.

Reference letters: *a*, Arteries in part with lymphoid sheaths; *cf*, fibrous capsule; *Kz*, germ centers; *Mk*, Malpighian corpuscles; *pl*, spleen pulp; *tr*, trabeculæ; *v*, vein in trabecula.

FIG. 2.—**Cross-section of Malpighian Corpuscle of Human Spleen.** × 100.

Technic and lettering as in Fig. 1.

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splenolymph glands. They possess a thin fibrous capsule, containing little elastic or muscle tissue. The blood sinuses are not so well developed. In the lymphoid tissue the eosinophilous and basophile cells are more numerous than in the other type. Large cells similar to those found in bone-marrow are now and then met with, as well as cells containing fragments of erythrocytes.

The **spleen** is surrounded by a firm fibrous *capsule*, consisting of fibro-elastic connective tissue and containing a few non-striated muscle-fibers, and is covered by the peritoneum. The capsule sends into the gland numerous trabeculæ of similar structure, which branch and anastomose to form the framework of the gland. The vessels of the spleen, and especially the veins, are associated with this framework. Professor F. P. Mall has recently shown that the trabecular and vascular systems together outline masses of spleen tissue, about 1 mm. in size, to which the name of spleen lobule has been given. Each lobule is bounded by three main trabeculæ, known as interlobular trabeculæ, which are parts of the general trabecular system of the spleen; from each of these arise three intralobular trabeculæ which by anastomosis form an intralobular framework, dividing the lobule into about ten smaller compartments. These compartments are occupied by a cellular tissue known as *spleen pulp*, arranged in the form of anastomosing columns or cords, known as *pulp cords* and consisting of a fibrous reticulum, resulting from

Tab. 24.

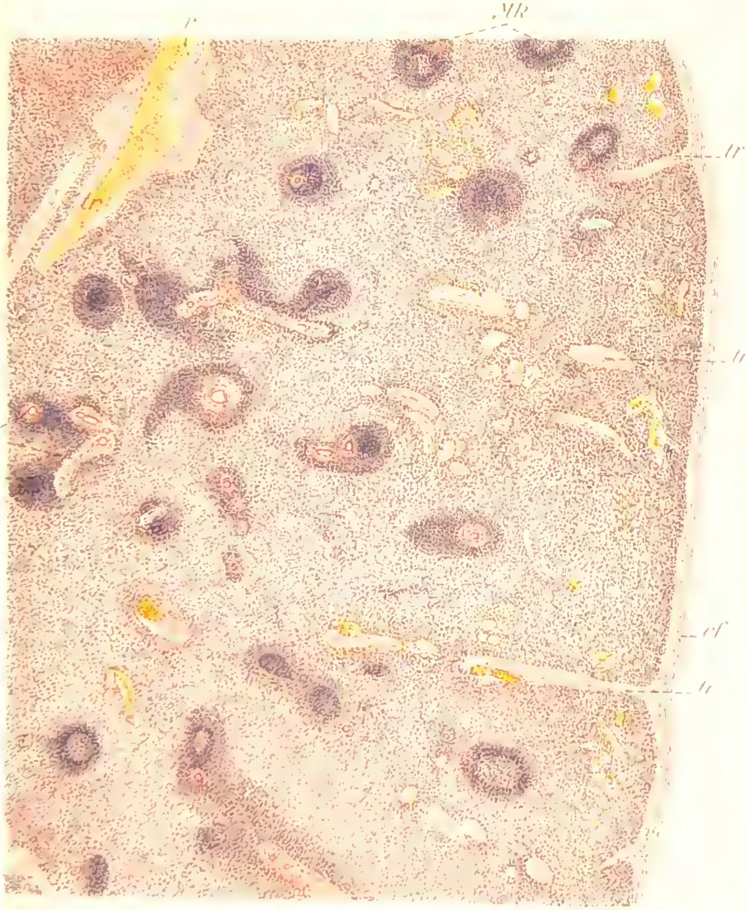

Fig 1.

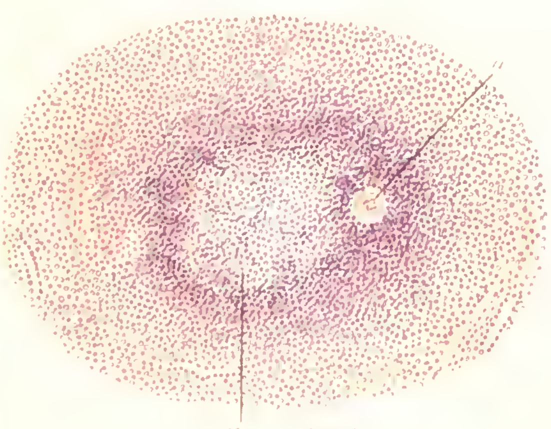

Fig. 2.

the further division of the trabecular system, in the meshes of which are found the spleen cells. Between the pulp cords there is found an anastomosing system of venous spaces. A terminal branch of the splenic artery enters at one end of the lobule and, passing up the center, gives off branches to the spleen pulp in each of the compartments. In each compartment this arterial branch divides repeatedly, the terminal branches coursing in the pulp cords and giving off numerous small branches, which expand to form the ampullæ of Thoma; these are only partly lined by endothelial cells, the wall of the remaining portion being formed by the reticulum of the spleen pulp. The ampullæ of Thoma are in communication with the venous spaces between the pulp cords. These venous spaces are the beginnings of the intralobular veins, which in turn empty into the interlobular veins associated with the interlobular trabeculæ. Throughout the spleen the veins are found in the trabeculæ, through which they leave the spleen at the hilum. The branches of the *splenic artery* enter the spleen at the hilum and for a distance are found in the trabeculæ; after leaving the trabeculæ the arterial branches divide repeatedly, forming a large number of tuft-like arterioles. Soon after leaving the trabeculæ, the adventitia of the arterial branches assumes the character of lymphoid tissue, which is here and there increased to form true lymph follicles with germ centers. These are the *spleen nodules* or follicles, or the Malpighian corpuscles, and in them the artery has generally an excentric position. Between the trabeculæ and Malpighian corpuscles is observed the spleen pulp. The larger vessels, especially the veins, are found in the trabeculæ.

In the meshes of the reticulum of the spleen pulp are found red blood-cells with now and then nucleated forms, the various kinds of lymphocytes and leukocytes, and especially a relatively larger proportion of mononuclear leukocytes; large mononuclear cells containing red blood-

PLATE 25.—THYMUS.

FIG. 1.—**Portion of a Cross-section of the Thymus Gland of a Fourteen-month-old Child.** × 20.

The figure shows a general view of the thymus with its lobules and connecting cords.

Technic: Müller's fluid. Alum-carmin.

Reference letters: *bg*, Blood-vessels; *cH*, Hassal's corpuscles; *lth*, thymus lobules; *mstr*, medullary cords; *sc*, cortical substance; *sm*, medullary substance.

FIG. 2.—**Hassal's Corpuscles from the Thymus of an Adult.** × 220.

The preparation was taken from a twenty-two-year-old man who had been executed.

Within the still well-developed thymus tissue the figure shows Hassal's corpuscles with the cells in part nucleated.

Technic: Zenker's solution. Hematoxylin-eosin.

Reference letters: *ek*, Epithelial nuclei; *HK*, Hassal's corpuscles; *lc*, leukocytes; *lt*, lymphoid tissue.

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corpuscles occur; these cells are often pigmented, and in carnivora are seen large polynuclear giant-cells, similar to those found in the bone-marrow.

There are but few *lymph-vessels* in the spleen. Afferent lymph-vessels are entirely lacking; efferent lymph-vessels occur, but pour their lymph into the *splenic sinuses*, which are therefore filled with blood and lymph.

The spleen contains numerous *non-medullated nerves*, which enter at the hilum in the form of small trunks and are no doubt vascular nerves. A few medullated nerve-fibers, probably sensory nerves, have also been traced into the spleen.

The **thymus** is a lymphoid organ, which is at first epithelial and represents a typical gland. In the course of development lymph-cells take the place of the glandular epithelium, which degenerates, with the exception of some epithelial remains. In this way an organ develops, the *parenchyma* of which is formed by *lymphoid cells* as in the lymph-glands and spleen, the form of an epithelial gland being, however, retained.

Connective-tissue trabeculæ separate a number of larger lobes from each other, which are connected by solid cords

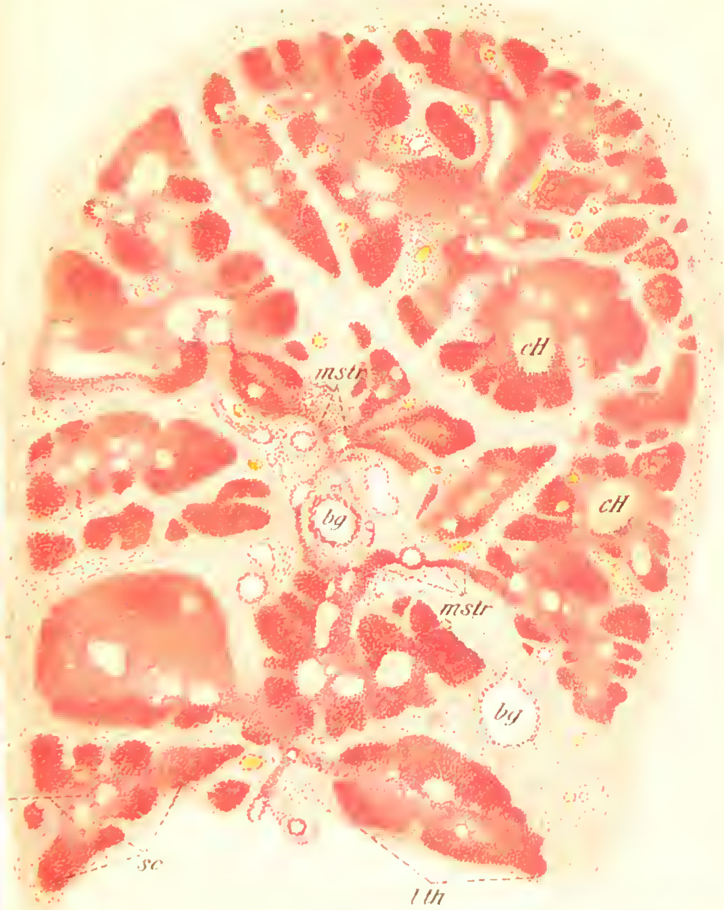


Fig. 1

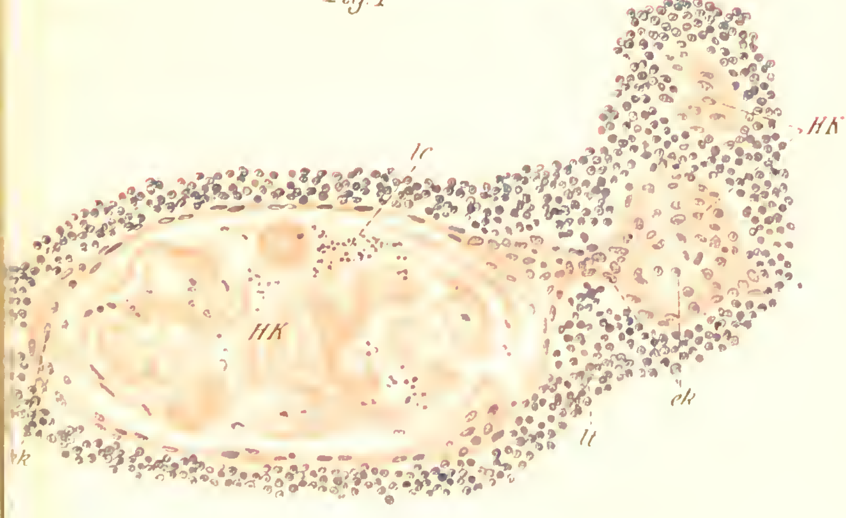


Fig. 2.

of cells, the so-called *medullary cords.* The larger lobes are more or less completely divided by connective-tissue septa into smaller lobules, which in form resemble the terminal divisions of alveolar glands. Each of these lobules of the thymus consists of an outer *cortical* and an inner *medullary substance;* generally several lobules are connected by means of the medullary substance. The cortical substance consists in the main of closely packed lymphoid cells; the medullary substance, of more loosely arranged cells and peculiar clear bodies, which generally show a distinctly concentric lamination, with nucleated cells in the interior; these are known as *Hassal's corpuscles.* They are regarded as the epithelial remains of the original epithelial gland. Likewise, epithelial nests may be occasionally found in the medullary cords, which consist mostly of lymphoid cells. These cords are the excretory ducts of the former glands, changed to lymphoid tissue.

The thymus is the only lymphoid organ which has no follicles with germ centers. As, nevertheless, mitotic divisions can be observed, it must be assumed that the thymus, like the lymph-glands and the spleen, serves for the new formation of lymphocytes and leukocytes. It is also thought that, as in the red bone-marrow, red blood-corpuscles are formed in the thymus. The thymus attains its highest development in childhood; later it is traversed by much fat tissue, but is often still well preserved in the adult.

The thymus receives many *blood-vessels,* which form capillaries in the medullary, as well as in the cortical substance. *Lymph-vessels* are also found; these form sinuses in the cortex of the lobules.

V. THE DIGESTIVE ORGANS.

The organs of the digestive system comprise a tubular structure, the digestive tract or intestinal canal, which begins at the mouth and ends at the anus, and the glands associated with it.

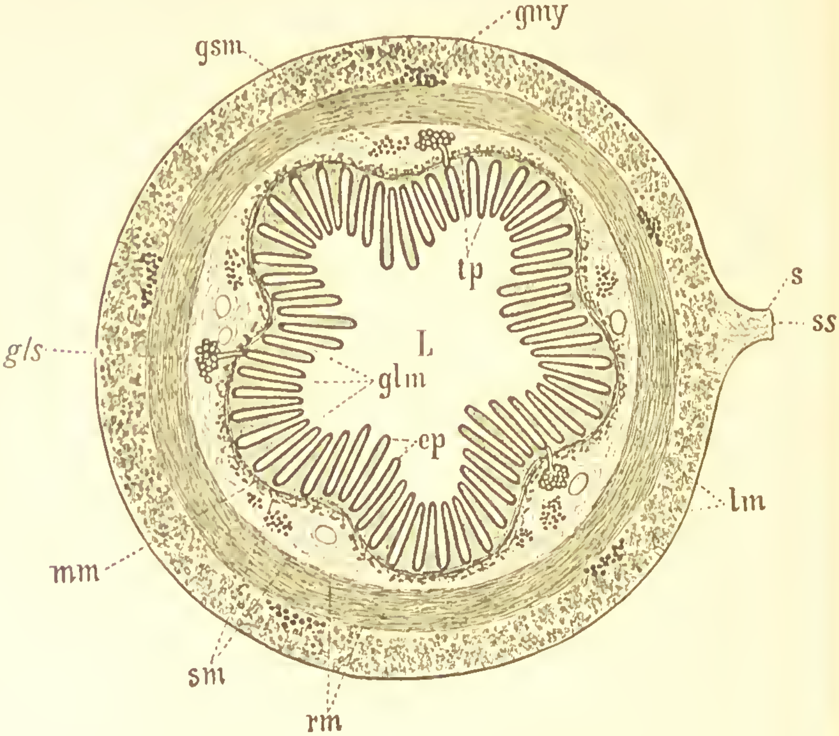


Fig. 43.—Diagram of digestive tract: *ep*, Epithelium; *glm*, glands of mucous membrane; *gls*, glands of submucosa; *gmy*, ganglion of myenteric plexus; *gsm*, ganglion of submucous plexus; *L*, lumen; *lm*, longitudinal muscle; *mm*, muscularis mucosæ; *rm*, circular muscle; *s*, serous coat; *sm*, submucosa; *ss*, subserosa; *tp*, mucosa.

The following layers or coats are recognized throughout the entire extent of the *intestinal canal:* (1) The mucous membrane, *tunica mucosa*, consisting of (*a*) the epithelium, (*b*) the tunica propria, which may contain straight or branched tubular glands and the ducts of glands lying in the submucosa, as well as solitary lymph-nodes, and (*c*) the muscularis mucosæ, consisting often of several layers of non-striated muscle. These three constituents of the mucous membrane are closely associated and take common part in the formation of its folds.

2. Beneath the mucosa is found the *submucosa*, consisting mainly of loose connective tissue. In it are found the larger blood-vessels and nerve trunks for the mucous membrane; in the duodenum it contains the secreting portions of Brunner's glands, and in the greater portion of the intestinal canal a portion of the solitary and aggregated lymph nodules, and also adipose tissue. Owing to the loose character of its tissue, the dislocation of the mucous membrane, formation of folds, etc., are rendered possible.

3. External to the submucosa is the *muscle layer* (muscularis), which is formed of non-striated muscle and often of several layers, generally of an inner circular and an outer longitudinal; between the two layers the muscular nerves form a plexus with ganglia.

4. The muscle layers are covered by the *serous layer*, which has on its surface a layer of mesothelial cells. Under the serosa there is loose connective tissue, the subserosa.

THE ORAL CAVITY.

The mucous membrane of the oral cavity is lined throughout with stratified squamous epithelium resting on a papillated mucosa. In some portions of the mouth the papillæ are very high and project into the epithelium, especially over the *gums* and at the *red margin of the lips*.

Since the mucous membrane of the mouth is not movable on its underlying portions, as in the hard palate, the submucosa is often formed of a closely woven connective tissue, which is firmly attached to the underlying tissue, as for instance the periosteum of the palate. A *muscularis mucosæ is lacking* in the mucous membrane of the entire

PLATE 26.—LIP.

Sagittal Section through the Upper Lip of a Man. × 6.

The preparation was taken from a man who had been executed.

The figure shows the layers of the lip under low magnification; skin, musculature, and mucous membrane, with the labial glands.

Technic: Müller's solution. Hematoxylin-eosin.

Reference letters: *a*, Arteria labialis superior; *gll*, labial glands; *Lr*, red portion of lip; *moo*, musculus orbicularis oris; *p*, hairs; *tp*, tunica propria, mucous membrane of the lip.

mouth cavity. The submucosa contains tubulo-acinous glands, the lip glands, palatal glands, etc. These will receive consideration at another place.

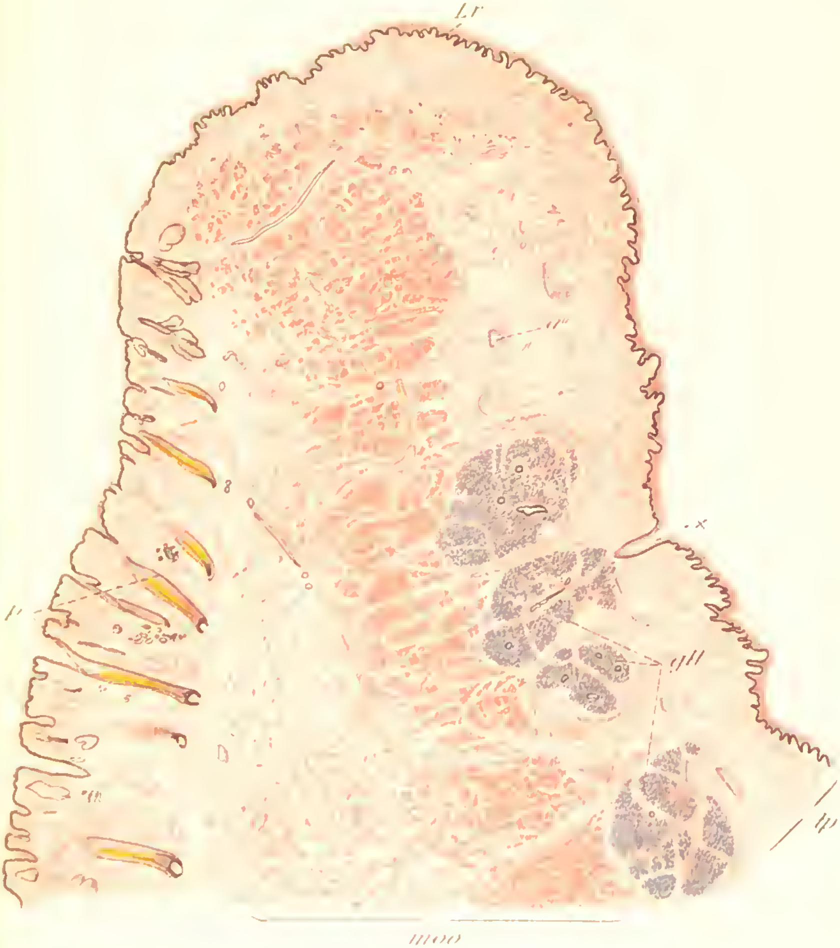
THE TEETH.

The *teeth* are of ectodermal origin and may be regarded as epidermal appendages; they are not developed from the entoderm as are the pharynx, glands and epithelium of the intestinal canal, as the portion of the mouth cavity developed from the oral pit in which the teeth are formed does not originally belong to the anlage of the intestines. Certain of the lower vertebrates have teeth in the skin.

The teeth are exceedingly hard structures, differentiated from epithelium and embryonic connective tissue. They contain in the interior a narrow space open toward the apex of the root of the tooth, the *tooth pulp*. Besides a few delicate connective-tissue fibers, the latter contains mainly the nerves and blood-vessels of the tooth and also a single layer of cubical cells forming the lining of the pulp cavity, which are arranged like epithelium and are

Fig. 44.—Longitudinal section of a molar tooth of man. × 8. The figure gives a general view of the structure of the tooth. The pulp cavity is not cut its whole length in the two roots seen in the section. We recognize the three main elements of the tooth—dentine, enamel, and cementum—and their division into crown and root. On account of the low magnification, the interglobular spaces appear only as a dark zone on the surface of the dentine. *C*, Cementum; *D*, dentine; *P*, pulp cavity; *S*, enamel.

Tab.26.



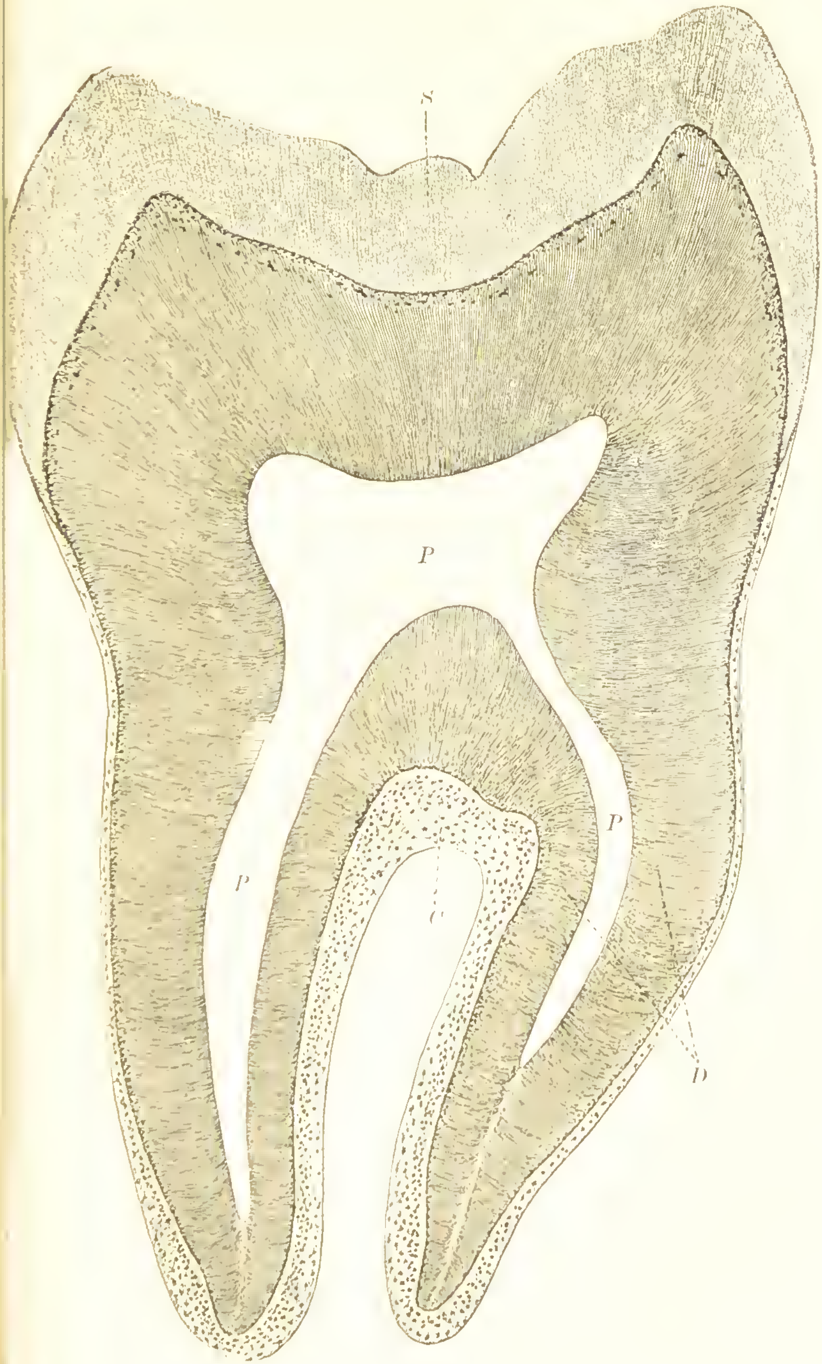


Fig. 44.

closely related to the osteoblasts of bone. They are here characterized as *odontoblasts.*

The tooth proper consists of three substances, of which one, the *enamel,* is of epithelial origin; the other two, the *dentine* and *cementum,* are of connective-tissue origin; the dentine forms the main mass of the tooth. Enamel and dentine are tissues which occur only in the tooth; the cementum, on the other hand, is bone tissue. In the three macroscopically distinguishable portions of the tooth—the crown, the neck, and the root—the three substances are so disposed that the dentine occupies the interior of the tooth in the crown as well as in the root, but nowhere reaches the surface of the tooth, while the enamel covers the dentine in the crown and ceases gradually toward the neck, and the cementum forms a narrow layer, beginning at the neck where the enamel terminates and increasing in thickness toward the root.

Dentine (substantia eburnea) resembles osseous[1] tissue in that it consists of a calcified ground substance with calcified fibrillæ, and of fine canals, the dentinal tubules, which radiate from the pulp cavity. Dentine differs from osseous tissue in that it contains no cells and no blood-vessels. In the dentinal tubules are found the processes of the odontoblasts, the *dentinal fibers,* which penetrate them for a variable distance. The fibrils of connective tissue in the calcified ground substance of the dentine are arranged mainly in the direction of the long axis of the tooth. The dentinal tubules or canals are fine canals, 4 μ in width at their opening into the pulp cavity, which, near the outer limits of the dentine, divide several times at an acute angle, and finally, giving off very fine lateral branches, lose themselves at the limits of the substance in fine, blindly ending branches.

In the region of the crown of the tooth, not far from the boundary line between dentine and enamel, there are

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[1] The osseous tissue of the teleosts is essentially a vascularized dentine.

Fig. 45.—Cross-section of a human canine. × 25. The figure shows under low power the relation of the dentinal tubules, of the granular layer (small interglobular spaces) and of the cementum. In the cementum we recognize numerous bone spaces; the dentinal tubules branch toward the granular layer. *C*, Cementum; *D*, dentine; *K*, granular layer; *P*, root canal (pulp cavity).

Fig. 46.—Portion of the crown of a longitudinal section of a human premolar. × 200. The figure shows the structure of a tooth at the border of enamel and dentine. In the region of the dentine two larger and two smaller interglobular spaces are shown. The dentinal fibers branch and fork and with their processes pass beyond the limits of the enamel. In the figure, the enamel prisms show partly wavy curves and partly alternating stripes of darker and brighter prisms (the parallel stripes of Retzius). *D*, Dentine; *Dk*, dentinal tubules; *Jg*, interglobular spaces; *S*, enamel; *Sp*, enamel prisms.

Fig. 47.—Portion of a longitudinal section of the root of a human molar tooth. × 200. The figure shows the structure of the boundary between dentine and cementum. In the cementum distinct bone spaces with bone canaliculi are seen. The dentinal tubules here show especially numerous divisions and lateral branches. The granular layer shows small, irregular interglobular spaces. *C*, Cementum; *D*, dentine; *Dk*, dentinal tubules; *K*, granular layer (small interglobular spaces); *KH*, bone spaces of the cementum.

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found irregular spaces bounded by spherical surfaces (in undecalcified tooth sections), which probably consist of dentine which has remained uncalcified. These are very variable and are designated as *interglobular spaces.* Similar but much smaller spaces are found at the borders of the dentine and cementum; they are beyond the ends of the dentinal tubules and form here a continuous limiting layer between dentine and cementum known as *Tomes' granular layer.*

The *enamel* consists of long six-sided prisms, the so-called enamel prisms, 3–6 μ in width, united by a small amount of cement substance. The enamel prisms are not straight, but present wavy borders, and run through the entire thickness of the enamel. They appear structureless, though occasionally they show striation and may be regarded as petrified epithelial cells. They contain almost no organic substance (3–5 per cent.) and dissolve entirely in mineral acids.

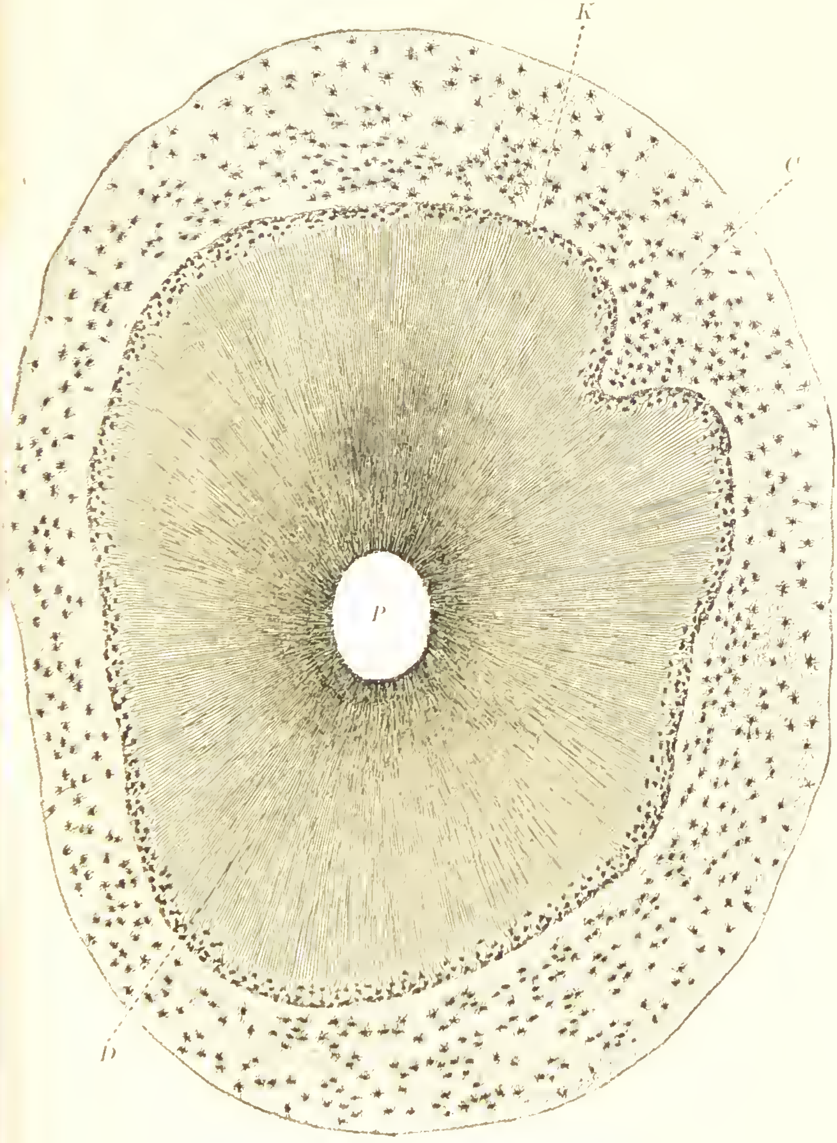

Fig. 45.

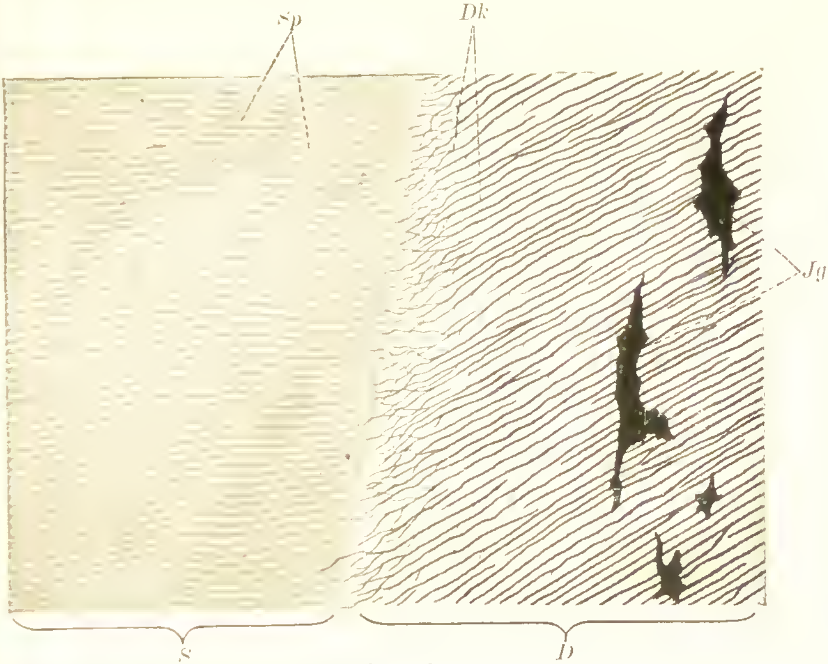

Fig. 46.

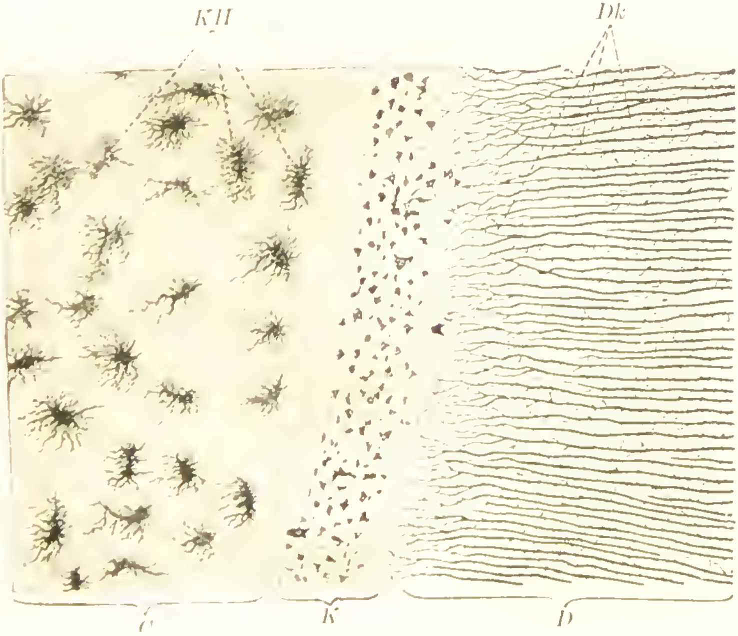

Fig. 47.

The surface of the enamel is covered by a structureless membrane, the *cuticula dentis.*

The *cementum* presents the structure of osseous tissue, usually, however, without showing the distinctive structure of compact bone—that is, without blood-vessels, Haversian canals, and concentric lamellæ. Only very large teeth have lamellæ in the cementum, as those of the larger mammalia. Then we find also Haversian canals. In man, lamellæ only very rarely occur. Where the cementum is thinnest, as in the neck, bone-corpuscles may be wanting.

The blood-vessels and nerves of the tooth are found in the pulp. The dentine is a tissue which is entirely free from blood-vessels and nerves, and the cementum is usually non-vascular. The enamel may be regarded as a dead substance, which undergoes no metabolism and needs no nourishment.

As has been previously stated (see page 130), the teeth differentiate partly from the epithelium of the oral cavity and partly from the connective tissue of the mucosa. The process of tooth development is introduced by the epithelium, which projects into the underlying connective tissue in the form of a continuous ridge, the *enamel ledge,* parallel to the margin of the jaw and not yet divided into tooth anlagen. This appears at the end of the second month of embryonal life.

Soon after the appearance of the enamel ledge there are found in certain places, which correspond in position and number to the deciduous teeth, collections of connective-tissue cells under the epithelial ledge; at the same time opposite these, nodular enlargements of the enamel ledge appear, the anlagen of the so-called *enamel organs,* while the collections of connective tissue cells represent the anlagen of the *dentinal papillæ.*

With simultaneous enlargement of the enamel organ and of the dentinal papilla by which the former more and more surrounds the latter in the shape of a cap, there is a con-

PLATE 27.—TOOTH DEVELOPMENT.

FIG. 1.—**Frontal Section through the Tongue and Lower Jaw of a Three-month Human Embryo (First Stage of Development of Tooth).** × 30.

The figure shows the cross-section of the tongue, of Meckel's cartilage, of the bone anlagen of the lower jaw, of the two dentinal ridges of the lower jaw, with the tooth anlagen.

Technic: Picrin-sublimate. Carmin-hematoxylin-eosin.

Reference letters: *M*, Meckel's cartilage; *m*, anlage of lower jaw; *pd*, papilla of tooth; *scho*, enamel organ; *Z*, tongue.

FIG. 2.—**Portion of a Cross-section of the Tooth Anlage of a Six-month Human Embryo (Third Stage of Tooth Development).** × 150.

The figure shows the formation of dentine on the part of the odontoblasts and of enamel on the part of the enamel cells. The enamel prisms are still separated by a relatively large amount of intercellular substance.

Technic: Müller's fluid-formalin. Hematoxylin-eosin.

Reference letters: *as*, External enamel cells; *D*, dentine; *ep*, enamel epithelium (inner enamel cells); *od*, odontoblasts; *pd*, papilla of tooth; *S*, enamel; *sp*, enamel pulp.

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striction and separation of the several tooth anlagen from the common enamel ledge, so that after a certain stage of development the tooth anlagen are connected to the ledges by a cord of epithelial cells. After the anlage of a deciduous tooth, consisting of enamel organ and dentinal papilla, is formed, this process is begun anew at the free lower edge of the enamel ledge for the formation of the anlage of the *permanent tooth*.

The epithelial enamel organ, surrounding in cap-like fashion the connective-tissue dentinal papilla, consists of a layer of cylindric cells with distinct cuticular border resting on the connective-tissue papilla, the so-called *inner enamel cells*, and an outer layer of flattened cells, the *outer enamel cells*. Between these two layers is found a tissue consisting of peculiarly modified stellate epithelial cells with a relatively large amount of mucoid intercellular substance, designated the *enamel pulp*. As the tooth develops, the enamel pulp gradually disappears.

The connective-tissue *dentinal papilla*, on the other hand, consists of mesenchymal tissue rich in cells, the upper layer

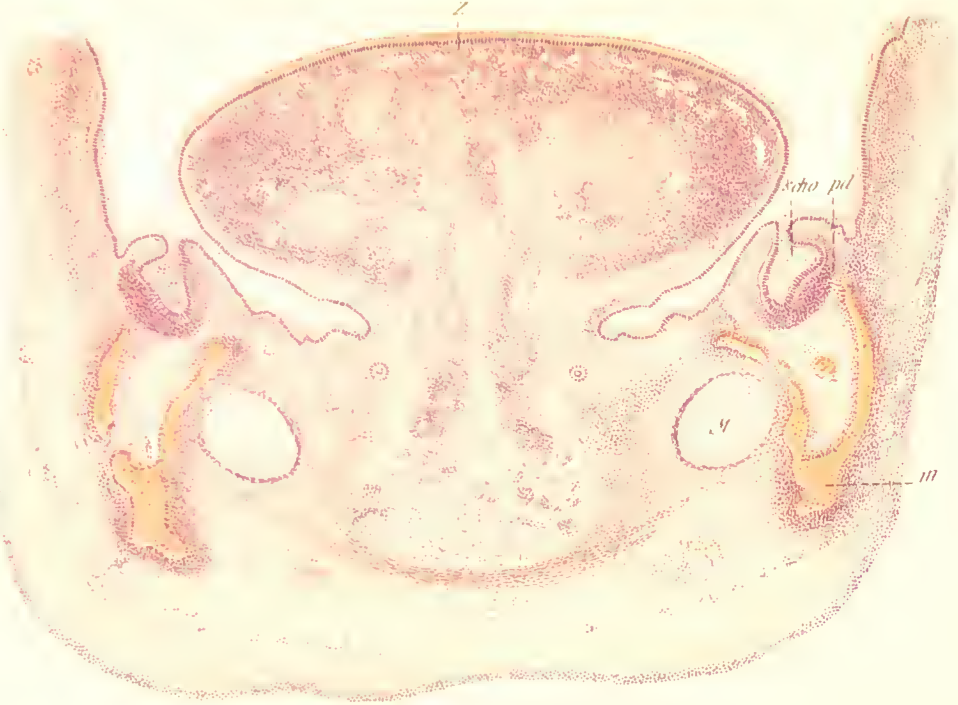

Fig. 1.

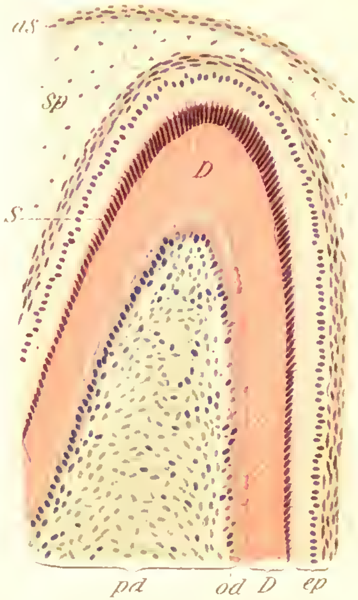

Fig. 2.

of which is formed of cells arranged like epithelium, the *odontoblasts.*

The entire anlage of the tooth is surrounded by a connective-tissue membrane, the so-called *dentinal sac.*

The dentine and enamel are developed as follows: The odontoblasts excrete dentine on the surface turned toward the enamel organ in a way similar to that in which the osteoblasts produce bone. The formation of enamel now begins by the excretion of enamel on the lower end, that turned toward the dentinal papilla, of the cells constituting the inner layer of enamel cells, which now show themselves as enameloblasts, since each separate cell forms a gradually elongating prism of enamel, in its beginning known as Tomes' process. The several prisms are separated at first by large amounts of cement substance. Young dentine and young enamel are thus contiguous. The further development of the two main hard substances of the tooth now goes on in such a way that the process reaches its highest development at the apex of the dentinal papilla, so that the apex of the crown and the crown itself are formed first. The enamel pulp is gradually resorbed and its place taken by the growing tooth. The inner enamel cells with their cuticular borders form the cuticula after the enamel formation is completed and the cells are destroyed. The outer enamel cells suffer the same fate. The tooth pulp is formed from the remains of the connective tissue papilla. The *cementum* arises from an ossification of the lower portion of the *dentinal sac.* The development of the permanent teeth is similar to that of the deciduous.

When the enamel and dentine formation has reached a certain stage, the epithelial cord between the tooth anlage and the enamel ledge disappears. Remains in the form of cellular strands are often retained for some time and form stratified epithelial bodies, the so-called glandulæ tartaricae.

PLATE 28.—TOOTH DEVELOPMENT.

FIG. 1.—**Longitudinal Section of a Deciduous Tooth Anlage of a Four-month Human Embryo (Second Stage of Development of Tooth).** × 40.

The figure shows a deciduous human tooth anlage before the beginning of the formation of dentine and enamel. On the free edge of the enamel ledge we see the anlage of the permanent tooth.

Technic: Picric acid sublimate. Hematoxylin-eosin.

Reference letters: *as*, External enamel cells; d_2, anlage of permanent tooth; *ep*, epithelium of mouth cavity; *is*, internal enamel cells; *k*, anlage of bone of lower jaw; *pd*, dentinal papilla; *sp*, enamel pulp; *Zs*, dentinal sac.

FIG. 2.—**Longitudinal Section of the Anlage of the Deciduous Tooth and of the Permanent Tooth of a New-born Child (Fourth Stage of Development of Tooth).** × 10.

The figure gives a general view of an older tooth anlage with well-advanced dentine and enamel formation, besides the anlage of the permanent tooth in the stage of Fig. 1. The latter is connected by remains of the enamel ledge with the epithelium of the mouth cavity.

Technic: Müller's fluid and formalin. Hematoxylin-eosin.

Reference letters: *D*, Dentine; D^I, deciduous tooth anlage; D^{II}, anlage of permanent tooth; *ep*, epithelium of mouth cavity; *gl*, glandula tartarica; *K*, bone of lower jaw; *pd*, papilla dentis; *S*, enamel partly separated from the enamel epithelium at the left; *sp*, enamel pulp.

THE TONGUE.

The *tongue* consists largely of striated muscle tissue surrounded by a mucous membrane which is firmly attached by means of an aponeurotic submucosa (fascia linguæ). We distinguish in the tongue an anterior papillary and a posterior tonsillar portion. In the anterior papillary portion there are found in man three forms of papillæ,—papillæ filiformes, papillæ fungiformes, and papillæ circumvallatæ. It is a misnomer to designate the projections on the tongue as *papillæ;* they are villi, which may themselves bear papillæ.[1] The fili-

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[1] By the term papilla is understood an arching of the connective tissue, for instance of the corium of the skin into the epithelium, without changing the superficial plane of the epithelium. Villi, on the other hand, are structures of the mucous membrane, which project above the surface and consist of connective tissue and epithelium. In the skin there are normally no villi; when they arise (warts and condylomata), they are pathologic.

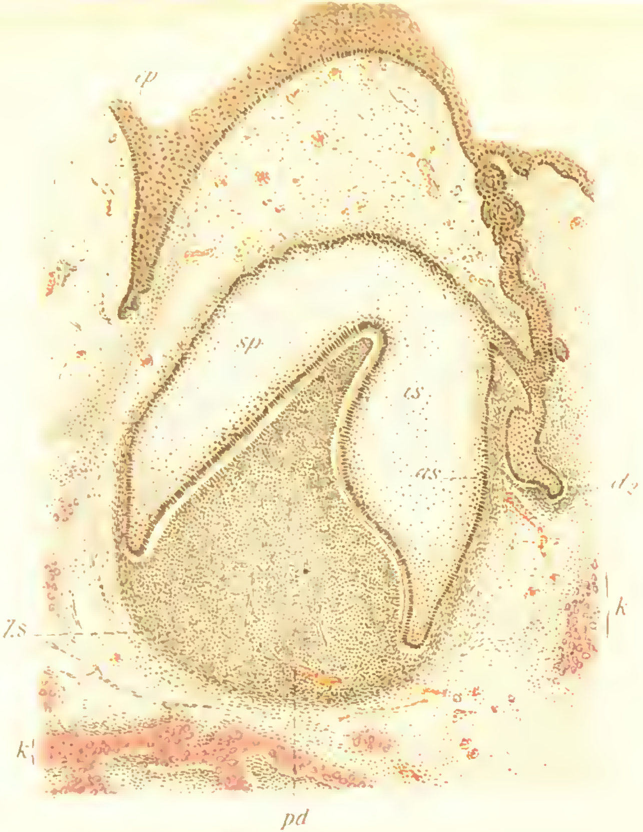

Fig. 1.

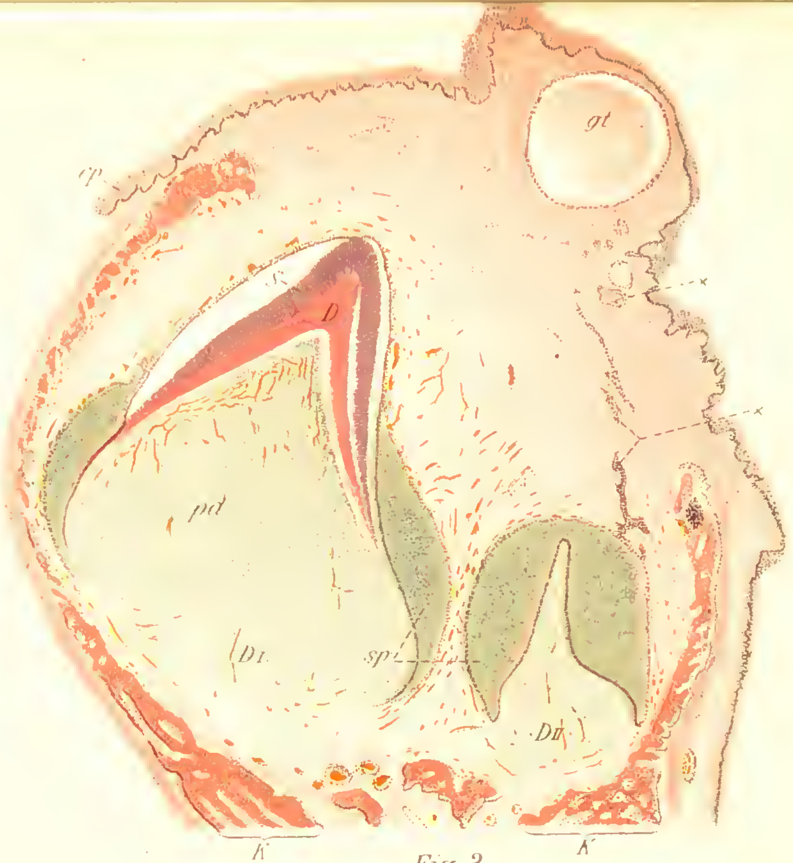

Fig. 2.

form and fungiform papillæ occur together on the entire papillary portion of the tongue, while the circumvallate papillæ are found in limited number near the tonsillar region.[1]

The *papillæ filiformes* consist of a connective-tissue fundament rich in elastic fibers and of a thread-like or conical form. This is covered by a thick epithelium, the superficial, flattened cells of which are arranged in many layers and form slender, partly cornified projections. They are the most numerous of the lingual papillæ. Usually they show three high secondary papillæ and on the surface a varying number of processes of horny cells.

The *papillæ fungiformes* have a broad connective-tissue foundation, with several often quite broad and generally not very high secondary papillæ on the surface; their epithelial covering usually presents a relatively smooth outer surface. Transition forms between the papillæ filiformes and the papillæ fungiformes are met with.

The *papillæ circumvallatæ* have the form of the fungiform papillæ, except that they are larger and are surrounded by an epithelial and connective-tissue wall, which bears no papillæ. Secondary papillæ are found on the upper and usually on the lateral surfaces. These are generally relatively few. The connective-tissue foundation of the papillæ circumvallatæ contains many nerve-fibers and also scattered ganglion-cells or groups of ganglion-cells (see Plate 31, Fig. 1). Numerous taste buds or gustatory organs are embedded in the epithelium covering the lateral surface and the wall surrounding the papillæ circumvallatæ.

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[1] The papillæ foliatæ, which are quite well developed at the side of the tongue in many mammalia, are quite rudimentary in man; they are structures consisting of a number of parallel folds of the mucous membrane and contain numerous taste organs.

PLATE 29.—TONGUE.

FIG. 1.—**Transverse Section through a Lingual Tonsil of Man.** × 30.

The preparation was taken from a man who had been executed.

The figure gives a general view of a lingual tonsil. The epithelium of the tonsillar crypt contains numerous leukocytes.

Technic: Müller's fluid. Hematoxylin-eosin.

Reference letters: *Bh*, Tonsillar crypt; *d*, excretory duct of gland; *ep*, epithelium; *nl*, lymph-nodes with germ center.

FIG. 2.—**Part of a Transverse Section of the Anterior Portion of the Human Tongue.** × 25.

The preparation was taken from fresh tissues, fixed two and one-half hours after death.

The figure shows transverse sections of filiform and fungiform papillæ.

Technic: Müller's fluid. Hematoxylin-eosin.

Reference letters: *m*, Musculature; *p*, secondary papillæ; *pfi*, papillæ filiformes; *pfu*, papillæ fungiformes; *tp*, mucous membrane; *sm*, submucosa (fascia) linguæ; *m*, muscle.

THE ADENOID STRUCTURES OF THE TONGUE AND OF THE PHARYNX.

The adenoid structures of this region belong to the class of superficial lymph nodules (see page 122). They are partly *solitary follicles,* as in the wall of the papillæ circumvallatæ, partly and most frequently agminated follicles. The latter form on the tongue the so-called *lingual tonsils*—folliculi linguales—and also the true *tonsils.*

The *lingual tonsils* are flat, wart-like elevations, which show in the middle a narrow but quite deep depression, the *tonsillar crypt.* The walls of the crypts consist of lymph-

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PLATE 30.—TONSILS.

Transverse Section through the Pharyngeal Tonsil of Man. × $6\frac{1}{2}$.

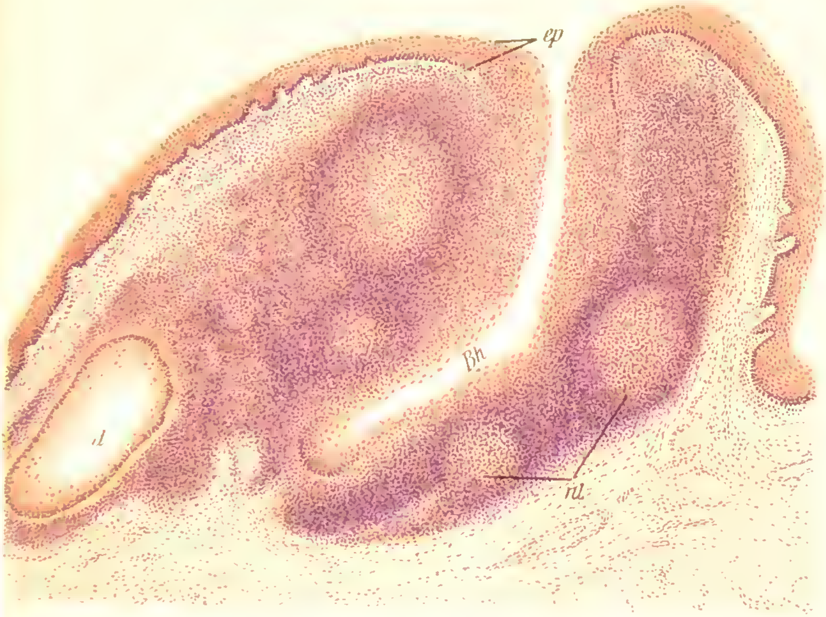
The preparation was taken from a man who had been executed.

The figure shows in longitudinal section the pharyngeal tonsil with its crypts, the lymphatic tissue, the connective-tissue septa, and the surrounding palatal muscle.

Technic: Zenker's solution. Hematoxylin-eosin.

Reference letters: *agp*, Arcus glosso-palatinus; *ep*, epithelium; *ft*, fossula tonsillaris; *M*, transversely striated muscle; *nl*, lymph nodules; *S*, connective tissue septa; *st*, remains of the tonsillar sinus.

Tab. 29.



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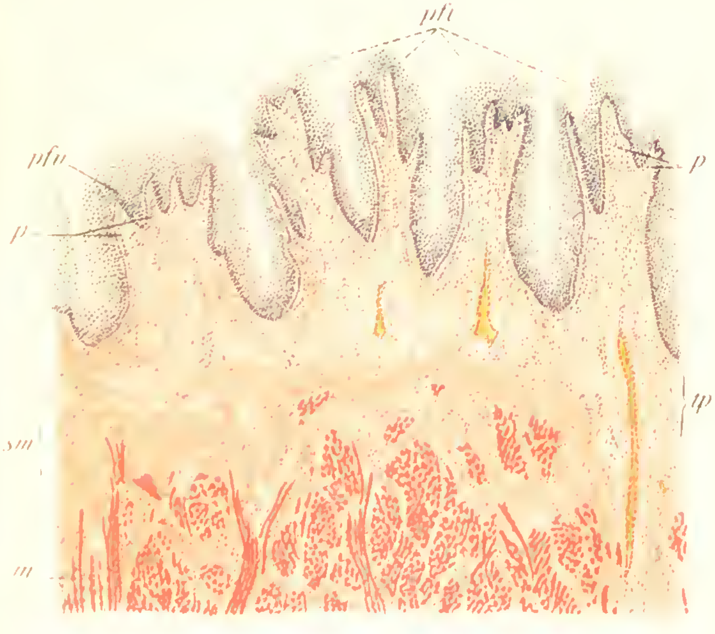
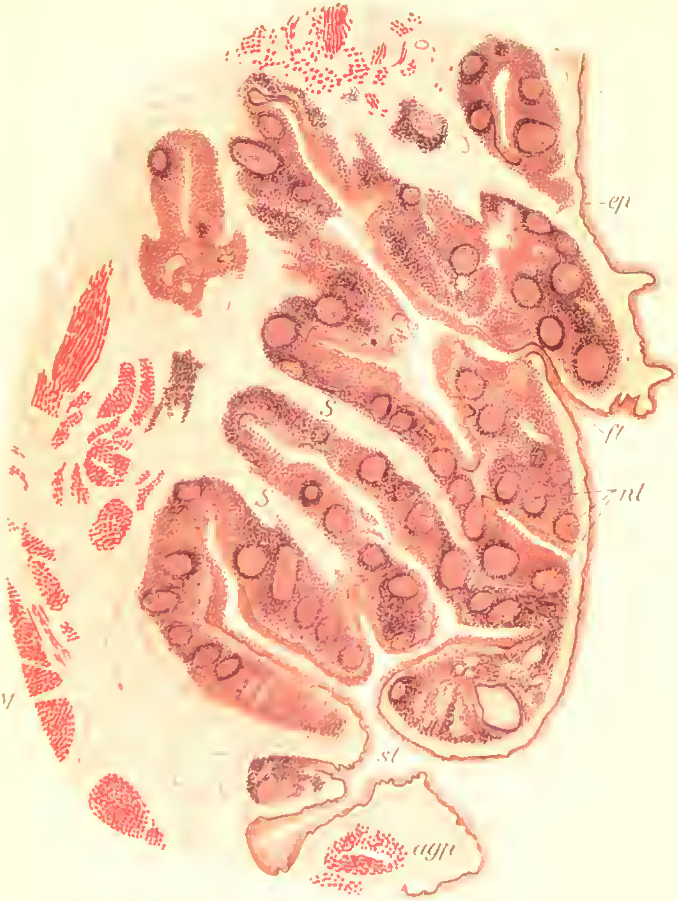


Fig. 2.

Tab. 30.



atic tissue with follicles and germ centers, which are sharply limited from the surrounding connective tissue of the mucosa of the tongue and from the musculature. The crypt is covered by the stratified pavement epithelium of the surface of the tongue; the latter is, however, broken through in many places by the leukocytes which are wandering out.

The *pharyngeal tonsils* are of similar structure, containing, however, a much greater number of lymph-nodes. Its lymphatic tissue is sharply separated from the closely adjacent muscle and from the mucous glands of the palatal arches. From the mucous membrane pass out many irregularly formed crypts, often widened at the base and provided with out-pouchings, the *crypts* or *fossæ* of the tonsil. All these are surrounded by lymphatic tissue, with secondary nodes and germ centers, and lined by stratified pavement epithelium. Connective-tissue *septa* extend from the underlying tissue of the tonsil into its lymphatic tissue, so that each crypt or fossa has a wall consisting of one layer of secondary nodules. The tonsil is thus divided by the connective-tissue septa into a number of separate compartments.

In the tonsils, as in all lymphatic tissues which are in connection with the epithelium, we can observe the *growth and migration of the leukocytes through the epithelium.* This process appears more distinct where it is connected with a stratified epithelium and where the leukocytes wander through in large numbers; this is the case in the tonsils. In the tonsillar crypts, certain areas of the stratified epithelium contain no leukocytes; in some regions the leukocytes are found singly between the epithelial cells, while in others, groups of leukocytes are found in the epithelium; finally areas occur where the leukocytes wander through in such numbers that the epithelium is entirely filled by them and only a few groups of epithelial cells are to be seen between large masses of leukocytes. In this process the papillæ of the mucous

PLATE 31.—TONGUE.

FIG. 1.—Transverse Section through a Papilla Circumvallata of the Human Tongue. × 40.

The preparation was taken from tissue fixed two and one-half hours after death.

The figure shows the structure of the circumvallate papilla, taste buds, and the serous glands surrounding it.

Technic: Zenker's solution. Hematoxylin-eosin.

Reference letters: *d*, Excretory duct of gland; *g*, ganglion-cells; *glser*, serous glands; *Gkn*, taste buds; *m*, transversely striated muscle-fibers; *n*, nerve-fibers of the glossopharyngeal nerve; *p*, secondary papillæ; *Rf*, circular furrow around the circumvallate papilla; *Rw*, circular wall of the papilla.

FIG. 2.—Transverse Section through a Portion of the Mucous Membrane of a Tonsillar Crypt. × 220.

The preparation was taken from one who had been executed.

The figure shows the wandering of the leukocytes of the mucous membrane through the epithelium. At the left, a few leukocytes in the epithelium; in the middle, there are several groups, and at the right the epithelium is so filled with leukocytes that the epithelial cells are found in the form of nests. The basement membrane of the epithelium can no longer be distinguished at the right.

Technic: Zenker's solution. Hematoxylin-eosin.

Reference letters: *dep*, Desquamated epithelial cells in the tonsillar crypt; *ep*, epithelium; *epr*, epithelial remains; *l*, leukocytes; *lg*, lymphoid tissue of the mucous membrane; *x*, leukocytes wandering into the lumen.

membrane first disappear; then, on account of the masses of leukocytes contained in it, the epithelium increases in thickness, and in places where the number of leukocytes exceeds the number of epithelial cells, the sharp boundary line between the epithelium and the lymphatic tissue of the mucous membrane disappears.

The *blood-vessels* of the tongue are very abundant and end partly in the musculature, partly in the mucous membrane. The capillary networks of the latter are found principally in the secondary papillæ, where, in tongues which are not coated,—that is, when the superficial, partly desquamated cells have been removed,—they shine through from their exposed position, imparting the normal redness to the tongue. The capillaries also form networks around the glands and pass into the tonsillar tissue.

The *lymph-vessels* of the tongue are most abundant in

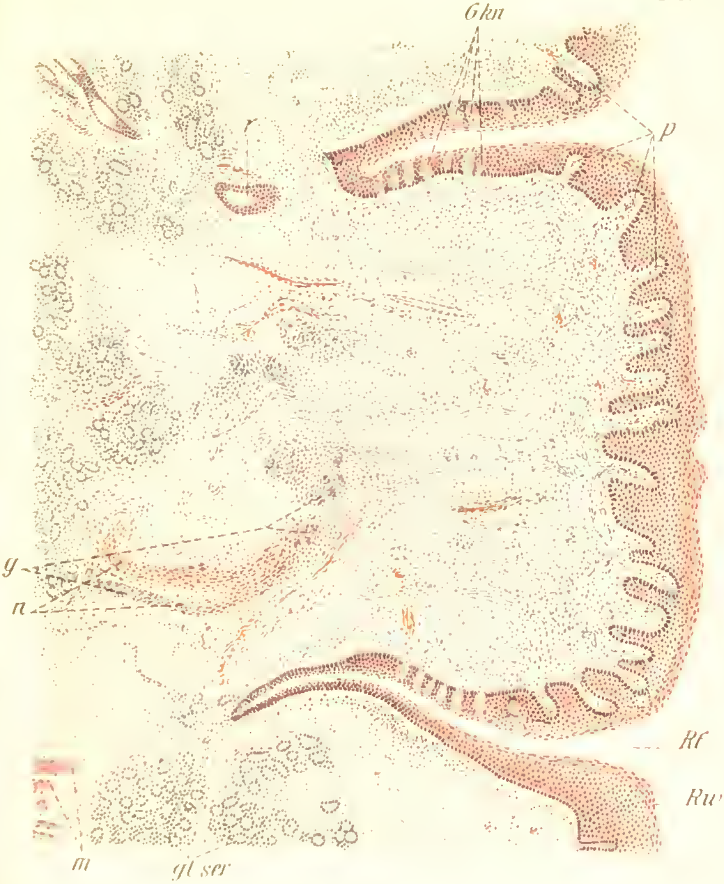


Fig. 1.

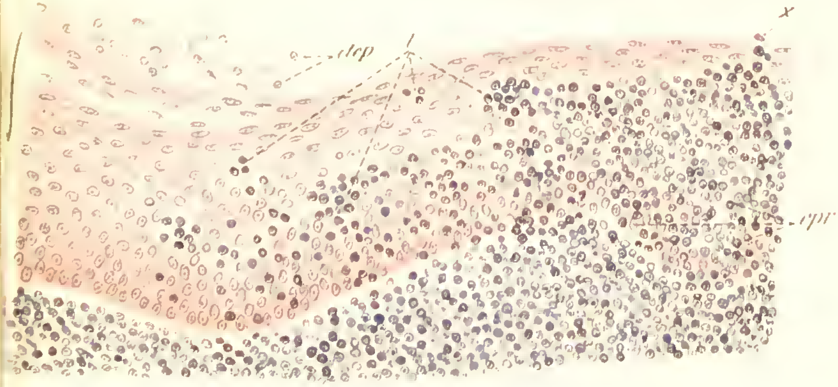


Fig. 2.

the tonsillar portion and form here a superficial network which surrounds the lymph nodules.

The *nerves* of the tongue, especially the branch of the glossopharyngeal going to the circumvallate papillæ, show small ganglia in their course. The tongue receives, besides the motor nerves and the nerves ending in the taste buds, branches of the lingual nerves which terminate in repeatedly branched endings in the epithelium.

THE ESOPHAGUS.

The *esophagus* has throughout a stratified pavement epithelium with papillæ. The *tunica propria* of the mucous membrane is composed of fibro-elastic connective tissue and contains small lymph-nodes, which are occasionally situated around the excretory ducts of the glands. The *muscularis mucosæ* is very well developed and consists almost entirely of longitudinal bundles. The entire mucous membrane, with the muscularis mucosæ, shows marked folds in the collapsed condition of the organ.

The *submucosa* of the esophagus is composed of very loose connective tissue, which often contains fat; in it are found small *mucous glands* and the larger nerve bundles and blood-vessels for the mucous membrane. The excretory ducts of the glands pierce the muscularis mucosæ and mucosa in which they are often surrounded by lymph follicles and open through the stratified pavement epithelium into the lumen. Serous or mixed glands are occasionally found.

Aside from the mucous glands, there also occur in the esophagus quite constantly glands which have the character of the fundus glands of the stomach; these are found especially in the region just before the junction with the stomach, and are therefore known as *cardiac glands;* occasionally they occur, however, in other portions of the esophagus and more frequently in the upper portion.

The *muscle* of the esophagus varies in different regions.

PLATE 32.—ESOPHAGUS.

Transverse Section of the Human Esophagus at the Level of the Middle Third. × 10.

The preparation was taken from a man who had been executed.

The figure shows a general view of the structure of the esophagus. The muscle is composed of a mixture of smooth and striped fibers.

Technic: Müller's fluid. Hematoxylin-eosin.

Reference letters: *ep*, Epithelium; *gl*, mucous glands of the submucosa; *L*, lumen; *Lm*, longitudinal muscle; *mm*, muscularis mucosæ; *nl*, lymph-node; *Rm*, circular muscle; *sm*, submucosa with fat-cells, blood-vessels, some longitudinal bundles of smooth muscle at the limits of the circular muscle; *ta*, tunica adventitia; *tp*, tunica propria.

In the upper portion, about one-third, it is composed of transversely striated elements; in the middle, of smooth and striated; and in the lower third, entirely of the non-striated variety. It shows a distinct inner circular and outer longitudinal layer. The muscle is surrounded on the outside by connective tissue, which forms an indistinctly bounded adventitia.

PLATE 33.—ESOPHAGUS, STOMACH.

FIG. 1.—**Portion of a Transverse Section of a Human Esophagus.** × 18.

The preparation was taken from one who had been executed.

The figure shows all the layers of the wall of the esophagus. The musculature consists of smooth and striped fibers mixed. In the mucous membrane a solitary lymph-node is found and mucous glands in the submucosa.

Technic: Müller's fluid. Hematoxylin-eosin.

Reference letters: *ep*, Epithelium; *gl*, glands; *glm*, non-striated longitudinal muscle; *lm*, longitudinal muscle (transversely striated); *mm*, muscularis mucosæ; *nl*, solitary lymph-node; *rm*, circular muscle (mixed); *sm*, submucosa; *tp*, tunica propria.

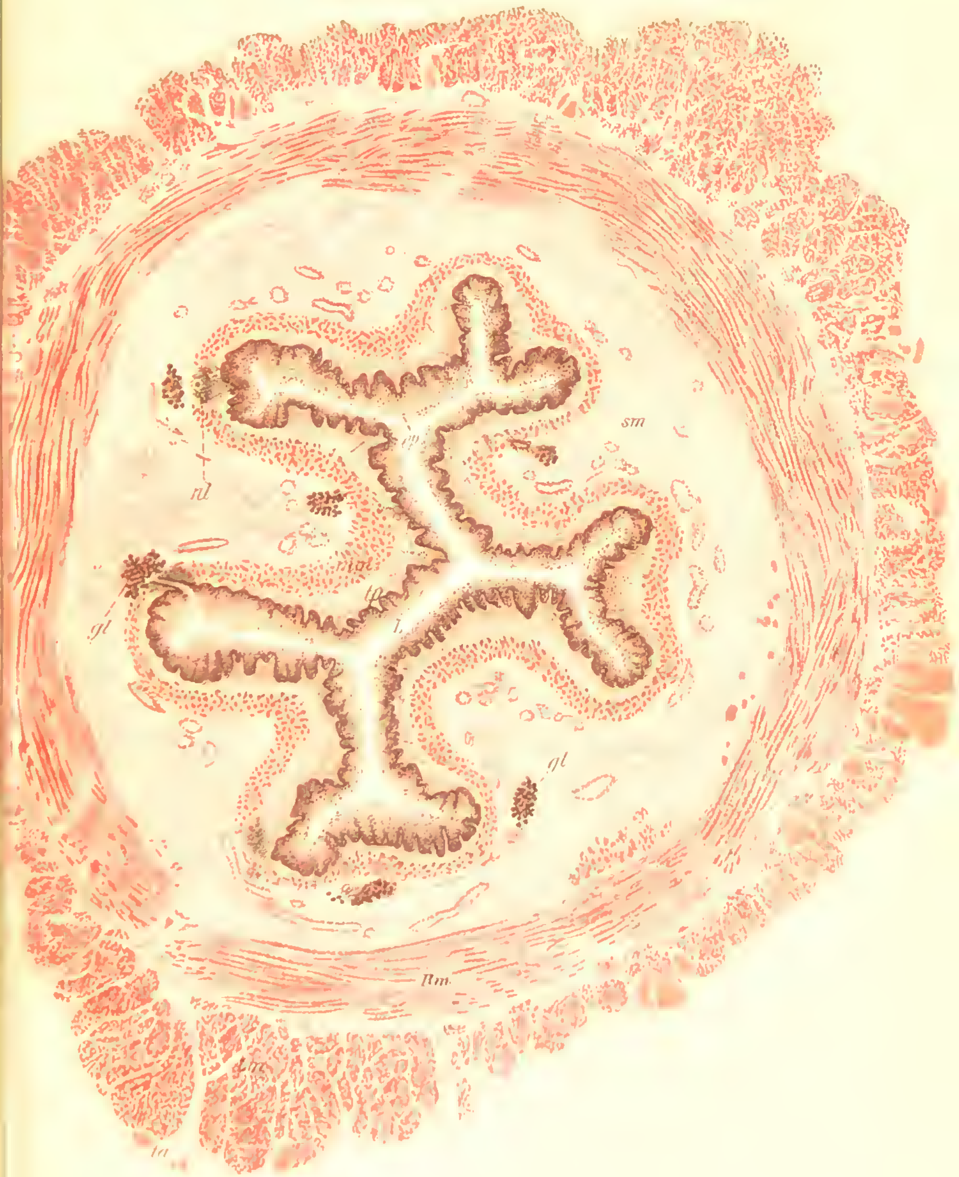
FIG. 2.—**Vertical Section of the Wall of the Stomach in the Region of the Pylorus.** × 20.

The preparation was taken from a man who had been executed.

The figure gives a general view of the layers of the wall of the stomach. The mucous membrane contains long crypts and short branched and twisted glands, as well as lymph-nodes.

Technic as in Fig. 1.

Reference letters: *a*, Artery of the submucosa; *fg*, gastric crypts; *M*, muscularis; *m*, mucosa; *mm*, muscularis mucosæ; *nl*, lymph-nodes; *sm*, submucosa.


ep
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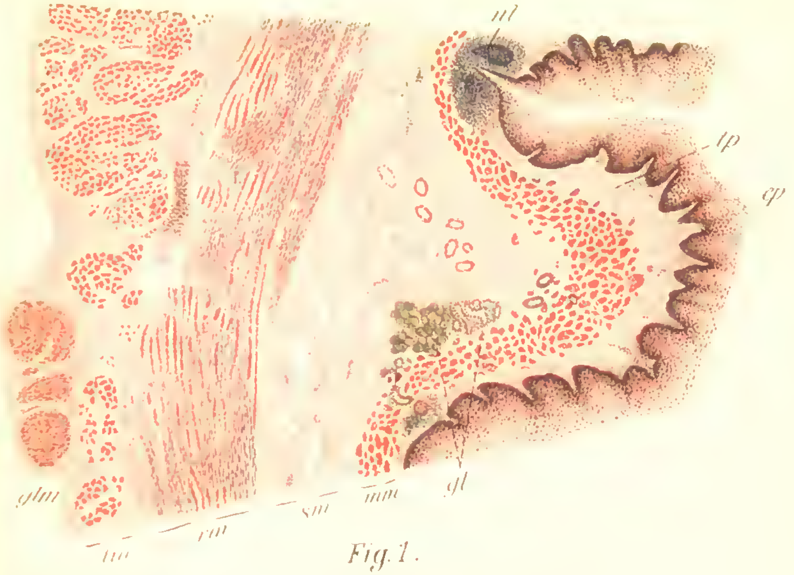

Fig. 1.

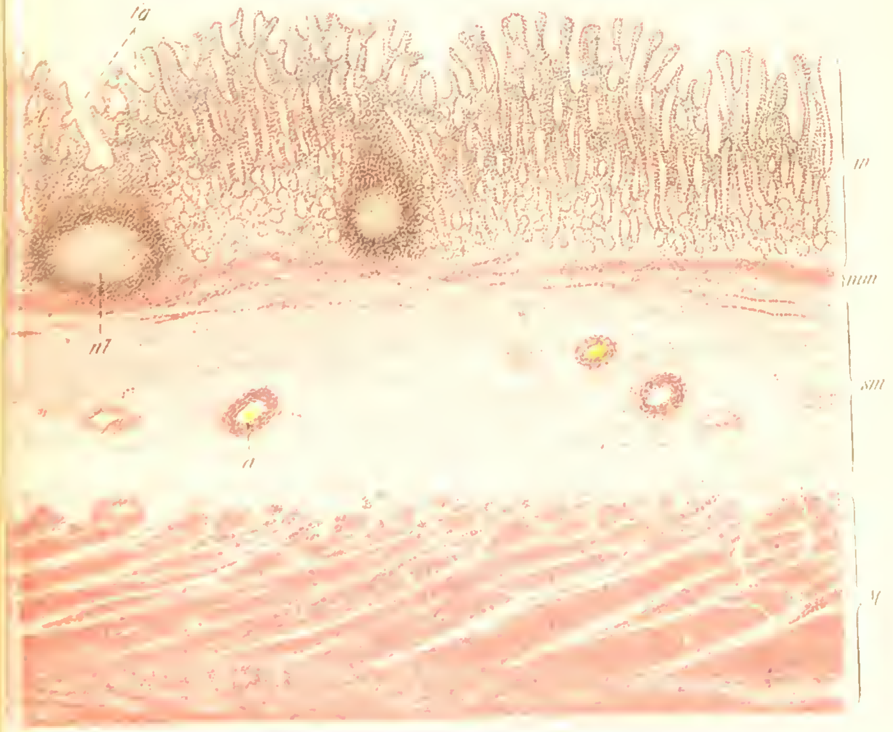

Fig. 2.

THE STOMACH.

The *wall* of the stomach shows in general the same layers as that of the esophagus, with the addition that the stomach is covered by peritoneum; so that a serosa and subserosa are added to the layers.

The *epithelium* of the surface of the stomach, which also lines the crypts in which the glands terminate, is columnar; cells are covered with mucus on the side toward the free surface and probably produce mucus like the goblet cells (see page 35).

The *tunica propria* of the stomach is composed mainly of *tubular glands* which open into the crypts; only a relatively small amount of interstitial tissue is found between them. The shape and structure of the glands in the region of the body of the stomach (cardiac portion, fundus, and body) differ from those observed in the portion toward the pylorus. We accordingly distinguish *fundus glands* or *glandulæ gastricæ propriæ* and *pyloric glands.* There is, however, no sharp boundary line between the two regions, but a gradual transition of one type of gland into the other. As the glands form the main portion of the mucous membrane, they impress upon it their typical character, so that we may speak of the fundus mucous membrane and the pyloric membrane.

In the *fundus region* the gastric crypts are smaller and shorter in proportion to the thickness of the mucous membrane than in the pyloric region; the glands of the fundus region are much less branched and the tubules are but little convoluted except at the base. Anastomosis between neighboring glands has been observed.

The fundus glands contain two kinds of cells—*chief cells* and *parietal cells.* The former may be regarded as continuations of the surface epithelium; they are relatively small and of nearly cubical shape. The *parietal cells* are large, round, or irregularly polygonal cells, have a distinctly granular protoplasm, and stain intensely with the

PLATE 34.—STOMACH.

FIG. 1.—**Transverse Section through the Mucous Membrane of the Fundus Region of the Stomach—General View.** × 45.

The preparation was taken from a man who had been executed.

The figure gives a general view of the mucosa of the stomach in the fundus region. We recognize the relation of the gastric crypts, of the glandulæ gastricæ propriæ, and in these the distribution of the parietal cells (stained yellowish-red).

Technic: Zenker's solution. Hematoxylin-orange.

Reference letters for Figs. 1-3: *bg*, Blood-vessels; *bz*, parietal cells; *cgl*, neck of gland; *fg*, gastric crypt; *fgl*, fundus of gland; *glg*, body of gland; *mm*, muscularis mucosæ; *nl*, solitary lymph nodule.

FIGS. 2 AND 3.—**Glands of Stomach under Somewhat Higher Magnification.** × 80.

Fig. 2 shows a distinct forking of a stomach gland; Fig. 3 a gland cut almost the entire length. Both preparations show the distribution of the parietal cells (reddish-yellow, *bz*) and chief cells (blue).

Technic and lettering as in Fig. 1.

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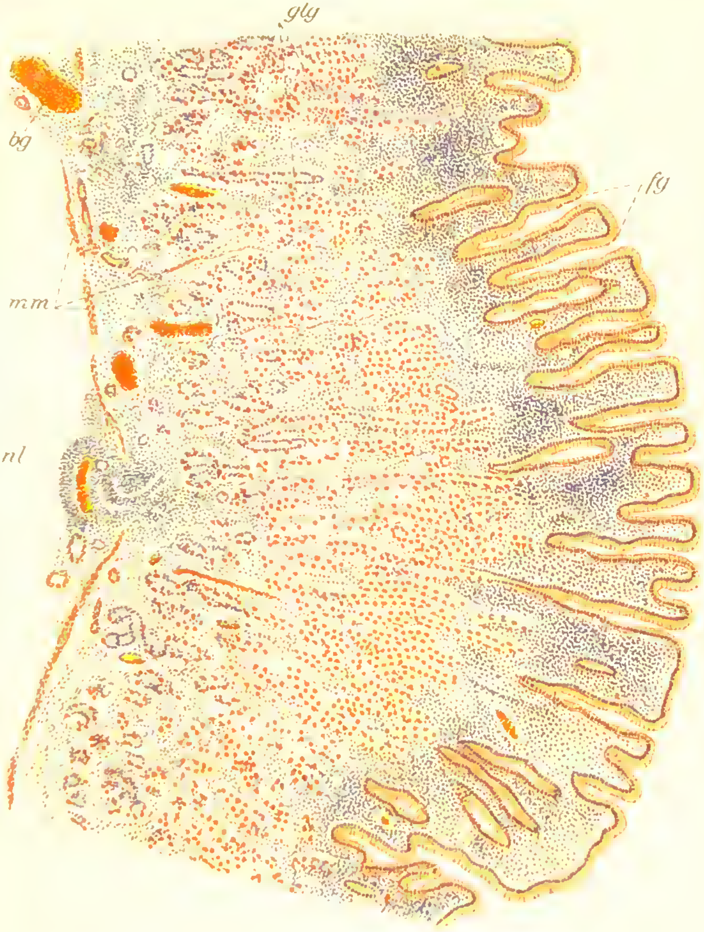
acid anilin dyes. The parietal cells are found abundantly between the chief cells, which they may equal in numbers or even exceed in the so-called neck of the gland—that is, the portion opening into the crypts; in the body of the gland they are scattered, and in the somewhat enlarged and slightly convoluted gland fundus, but few are found. The latter portion of the gland is therefore formed almost entirely of chief cells. Between the chief cells, intercellular and in the parietal cells, intracellular secretion capillaries are found (see page 36).

The *pyloric glands* open into relatively wide and deep crypts. The glands are shorter than those of the fundus region; they are more branched and more convoluted, especially at the base. They contain only one form of cell, similar to the chief cells of the fundus glands. Occasionally, however, scattered parietal cells are found in this region. The portion of the mucous membrane of the stomach not occupied by glands is filled by reticular connective tissue rich in lymph-cells, into which single muscle-fibers of the muscularis mucosæ extend.

The lymph-cells form—more frequently in the pyloric

Tab. 34.



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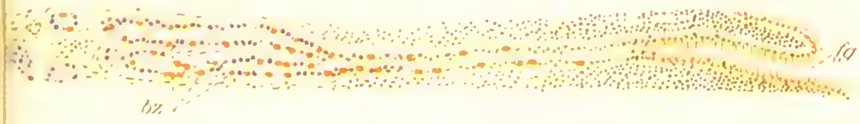

Fig 2.

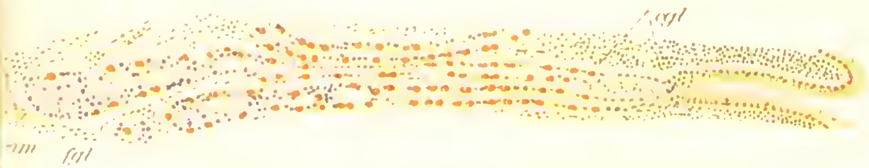

Fig. 3.

region—collections of solitary nodes, which are situated chiefly in the deeper layer of the mucous membrane. In the *muscularis mucosæ* of the stomach, two layers can be distinctly recognized—a circular and a longitudinal layer. The *submucosa* is like that of the esophagus; it is composed of loose connective tissue, with many elastic fibers and some adipose tissue. It also contains the blood-vessels and nerves for the mucous membrane. The *muscular coat* of the stomach consists of smooth muscle, which, in the main, is arranged in two layers, an inner circular and an outer longitudinal layer. To this, however, is added the radiation of the musculature of the esophagus, which complicates the lamination of the muscular coat of the stomach.

The *serosa* of the stomach is covered by a layer of mesothelial cells.

THE SMALL INTESTINE.

In its whole course the *small intestine* shows in general a very uniform structure and the same lamination as the stomach. This is complicated only in the upper portion of the intestine by the duodenal glands. The mucous membrane of the small intestine is characterized by the presence of *villi* (see page 136). The villi are high and large, and at the same time somewhat flattened at their beginning in the duodenum (occasionally they begin in the stomach close to the pylorus), and extend to the valvula colica. The villi of the ileum are much smaller and more conical. They consist of slender processes of mucous membrane, which are covered by epithelium. The *epithelium* of the entire intestinal canal, from the pylorus to the anus, is a simple columnar epithelium with striated cuticular border (see page 33). The form of the cells, more especially at the apex of the villi, is generally prismatic. *Goblet cells* also occur in varying number (see page 35). Both forms of cells are found in the beginning of

PLATE 35.—STOMACH, DUODENUM.

FIG. 1.—**Portion of a Tangential Section of the Mucous Membrane of the Human Stomach (Fundus Region).** × 300.

The preparation was taken from a man who had been executed.

The figure shows the transverse sections of five fundus glands and the relation of the chief and parietal cells to the lumen.

Technic: Zenker's solution. Hematoxylin-eosin.

Reference letters for Figs. 1 and 2: *bz*, Parietal cells; *hz*, chief cells; *l*, lumen; l_1, process of lumen between the parietal cells; *tp*, connective-tissue cells of the tunica propria.

FIG. 2.—**Portion of a Longitudinal Section of a Fundus Gland.** × 300.

Legend and lettering as in Fig. 1.

FIG. 3.—**Portion of a Transverse Section of the Human Duodenum.** × 40.

The preparation was taken from a man who had been executed.

The figure shows the relation of the duodenal glands (Brunner), of the villi, and the lamination of the intestine.

Technic: Potassium chromate and formalin. Hematoxylin-eosin.

Reference letters: *gld*, Duodenal glands (Brunner); *gli*, intestinal glands (Lieberkühn); *gsm*, ganglion of the submucous plexus; *M*, muscularis (circular and longitudinal layers); *mm*, muscularis mucosæ; *Mu*, mucous membrane; *SM*, submucosa; *vi*, villi; ×, places where the duodenal glands have broken through the muscularis mucosæ.

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the short tubular glands, the glands of Lieberkühn, which lie in the tunica propria of the small intestine. Under the epithelium is a structureless basement membrane, which, as it occasionally contains distinct nuclei, is probably of connective-tissue origin. The epithelial cells in the lower portion of Lieberkühn's glands, the deepest cells forming the real fundus of the gland, show a distinct granulation of their protoplasm similar to that of gland-cells (see page 35), probably a preliminary stage of the secretion (zymogen, so-called *Paneth's cells*). The adjoining cells generally show mitotic division, more often seen in the small intestine than in the large intestine. The nuclei of the cells undergoing mitotic cell division always lie near the lumen of the gland. The resulting cell proliferation serves the purpose of regenerating the intestinal epithelium, in that the cells are pushed from the depths of the gland toward the surface of the villi. The cells thus

Tab. 35.

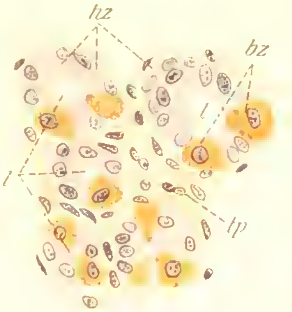

Fig. 1.

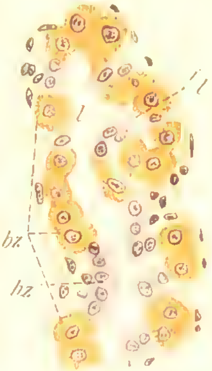

Fig. 2.

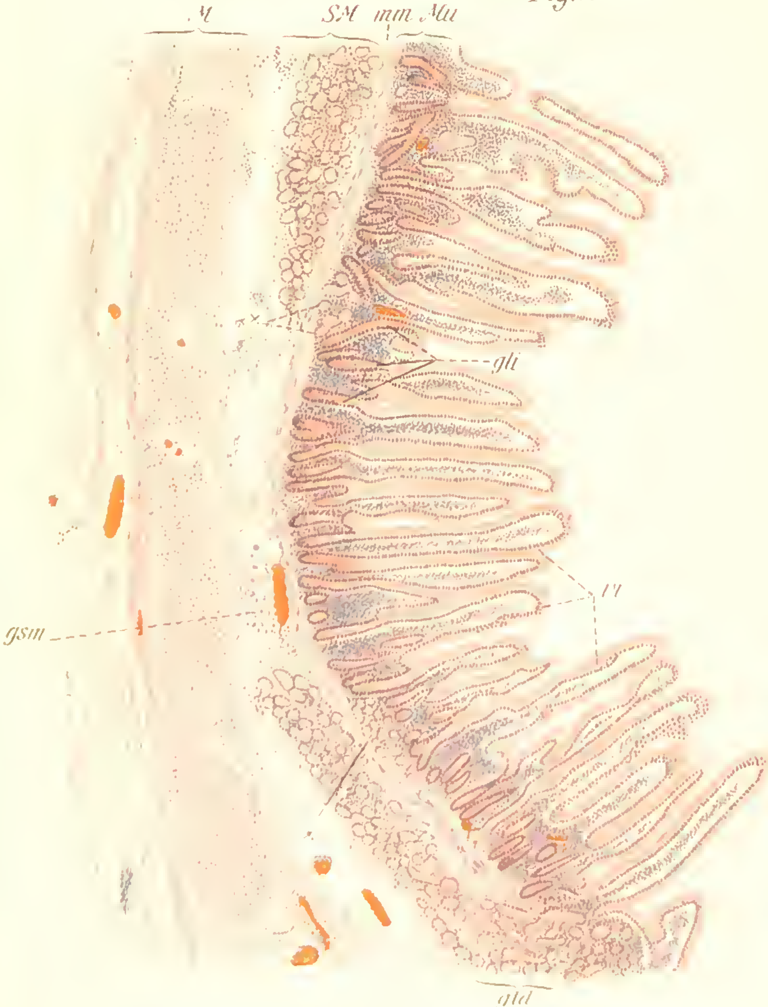

Fig. 3.

pushed up serve to replace the goblet-cells which degenerate. It should, however, be remembered that the evacuation of the secretion of a goblet-cell does not necessitate its degeneration; on the contrary, it is more than probable that there is no relation between the number of mitoses in the intestinal glands and the number of goblet-cells; rather, when the number of the latter increases, the number of the former decreases. In the ciliated epithelium of the respiratory tract, the goblet-cells are often very abundant, while mitoses are entirely lacking.

The *tunica propria* of the small intestine is a reticular connective tissue and fills the interstices between the intestinal glands or glands of Lieberkühn and forms the greater portion of the villi. In the long axis of the latter lies the *axial villous space* or the *central chyle vessel*, the radicle of the lymph-vessels of the small intestine; the villi also contain blood capillaries and some non-striated muscle-fibers, which extend from the muscularis mucosæ into the villus (see Plate 39). The portion of the tunica propria lying between the intestinal glands as well as that of the villi is rich in leukocytes.

The *muscularis mucosæ* of the small intestine is well developed and consists usually of two layers, an inner circular and an outer longitudinal.

The *submucosa* of the small intestine consists of loose connective tissue and in it are found blood-vessels and a nerve plexus (see below). Fine vascular processes of the submucosa project into the *plicæ circulares* (Kerckring's folds) formed of the entire mucous membrane, including the muscularis mucosæ.

The *muscular coat* of the small intestine is arranged in two distinctly separated layers, an inner circular and an outer longitudinal. The latter is covered by the serosa, which has the same structure as that covering the stomach.

The upper end of the *duodenum* has a somewhat different structure from that of the remaining portion of the small intestine, by reason of the fact that the picture is

PLATE 36.—SMALL INTESTINE.

Portion of a Longitudinal Section through the Human Jejunum. × 15.

The preparation was taken from a man who had been executed.

The figure shows the transverse section of the entire intestinal wall with all its layers. Two valvulæ conniventes (Kerckring's folds) are seen in the section. The submucosa extends into these.

Technic: Absolute alcohol. Hematoxylin-eosin.

Reference letters: *bg*, Blood-vessels (veins of the submucosa); *lm*, longitudinal muscle; *mm*, muscularis mucosæ; *nls*, solitary lymph nodule; *rm*, circular muscle; *sm*, submucosa; sm_1, submucosa of Kerckring's folds; *vi*, villi.

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here complicated by the *duodenal glands* in the submucosa. In this portion of the duodenum, therefore, glands are found in the submucosa as well as in the mucosa. The duodenal glands, unlike those of the intestine, which are straight tubules, are simple branched alveolo-tubular glands. The cells of the terminal portion are similar to those of the pyloric glands, on the one hand, and to the mucous cells of the salivary glands, on the other hand. Their excretory ducts penetrate the muscularis mucosæ and mucosa propria and open either into an intestinal gland or on the

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PLATE 37.—SMALL INTESTINE.

FIG. 1.—**Portion of a Transverse Section of the Mucous Membrane of the Human Small Intestine.** × 80.

The preparation was taken from a man who had been executed.

The figure shows the longitudinal section of four villi, a number of intestinal glands, the lymphoid mucous membrane, and the muscularis mucosæ.

Technic: Absolute alcohol. Hematoxylin-eosin.

Reference letters: *ep*, Epithelium; *gli*, intestinal glands (Lieberkühn); *m*, smooth muscle-fibers of the villi; *mm*, muscularis mucosæ; *tp*, tunica propria.

FIG. 2.—**Portion of a Section of the Mucous Membrane of the Human Small Intestine (Duodenum).** × 300.

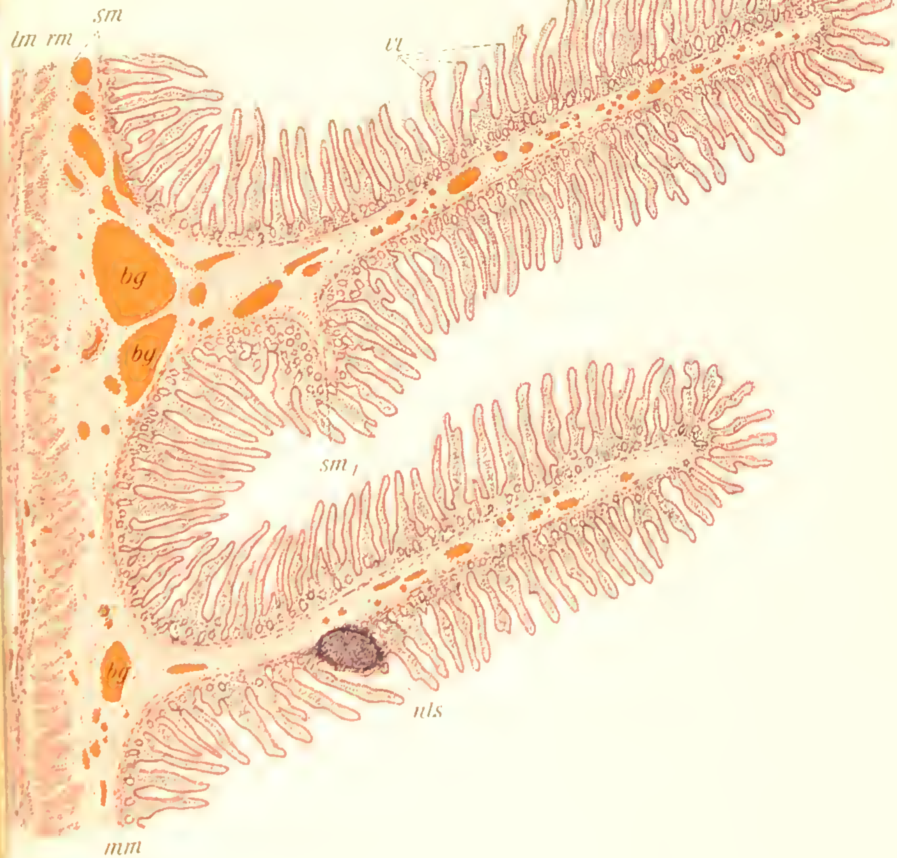
The preparation was taken from a man who had been executed.

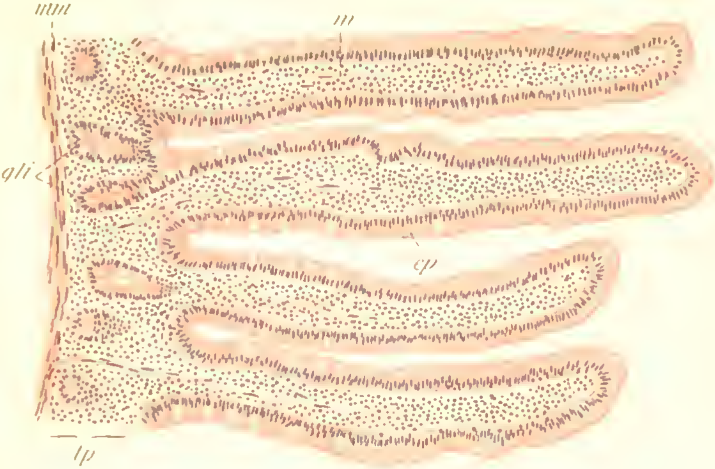
The figure shows the longitudinal section of two intestinal glands, and the condition of the epithelium in these.

Technic: Potassium chromate-formalin. Hematoxylin-eosin.

Reference letters: *bz*, Goblet-cells; *el*, eosinophile leukocytes; *ep*, epithelium with cuticular border (edge of villi); *lgli*, lumen of intestinal gland; *mi*, mitoses of epithelial cells of intestinal gland; *Pz*, cells of Paneth with granulation.

Tab. 36.





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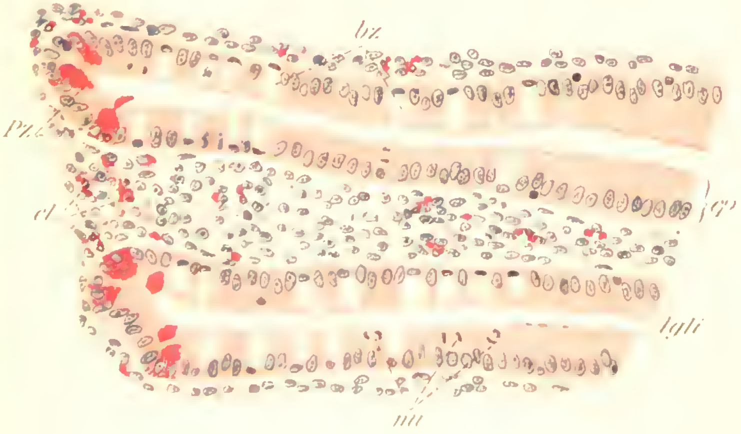

Fig. 2.

free surface of the mucous membrane. In man, often considerable portions of the duodenal glands (in the neighborhood of the excretory ducts) lie within the muscularis mucosæ and therefore in the region of the mucous membrane.

THE LARGE INTESTINE.

The wall of the *large intestine* differs in structure from that of the small intestine in that the villi are lacking and that the intestinal glands are longer, increasing in length as we pass from the cecum toward the rectum. The glands of the large intestines contain numerous goblet-cells toward the base of the glands, especially in the central portion, while the superficial epithelium and the mouths of the glands have few goblet-cells; this is in marked contrast to the condition of the small intestine, where the majority of the goblet-cells are found in the epithelium of the villi. Except in the rectum, the longitudinal muscle of the large intestine is arranged in three bundles or stripes, the tæniæ coli.

THE LYMPHATIC STRUCTURES OF THE INTESTINES.

The lymphatic structures of the intestinal canal appear in the form of solitary follicles and agminated glands or Peyer's patches. The latter are found only in the lower portion of the ileum, the former occur in the entire intestinal tract, large as well as small, being more frequent in the large intestine and ileum than in the jejunum. In the small intestine, as in the stomach, the solitary follicles are situated in the mucosa; the villi are wanting over their pear-shaped apices, which are in close relation to the epithelium. In the large intestine the broader portion of the follicle is in the submucosa—that is, it generally pushes the muscularis mucosæ markedly into the submucosa. The follicles usually contain germ centers.

The *Peyer's patches* are elongated structures consisting

PLATE 38.—LARGE INTESTINE.

FIG. 1.—**Transverse Section through the Entire Wall of the Large Intestine (Descending Colon).** × 30.

The preparation was taken from tissue fixed two and one-half hours after death.

The figure shows the lamination of the wall of the large intestine.

Technic: Tellyesnicky's fluid. Hematoxylin-eosin.

Reference letters: *ep*, Epithelium; *gli*, intestinal glands; *gmy*, ganglion of the myenteric plexus; *lm*, longitudinal muscular layer; *mm*, muscularis mucosæ; *sm*, submucosa; *rm*, circular muscular layer; *tp*, tunica propria.

FIG. 2.—**Portion of a Transverse Section of the Mucosa of the Human Rectum.** × 60.

The preparation was taken from a convict who had been executed.

The figure shows the mucous membrane of the rectum with the glands of Lieberkühn and a solitary follicle. The broader end of the latter is apparently in the submucosa, but in reality it only pushes the muscularis mucosæ into the submucosa.

Technic: Zenker's fluid. Hematoxylin-eosin.

Reference letters: *epl*, Epithelium filled with leukocytes; *gli*, glandulæ intestinales; *kz*, germ centers; *m*, single muscle-fibers in the mucous membrane; *mm*, muscularis mucosæ; *nl*, solitary lymph-node; x, section of intestinal glands.

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of from ten to sixty adjacent solitary follicles connected by their cortical zones. The follicles are spread out so that they lie in a single layer and almost entirely in the mucosa; the apices, however, project as broad lymphoid villi into the mucous membrane and into the intestinal lumen. The villi are lacking over the Peyer's patches (see Fig. 48).

In the *vermiform process* the arrangement is similar; the mucous membrane is rudimentary, consisting of only a few glands, while the lymphatic tissue predominates in the form of closely crowded solitary follicles with germ centers. The solitary follicles and lymphatic structures of the intestine contain only blood capillaries—no lymph capillaries at least in man. In the places where the crowns of the solitary follicles or agminated follicles come in contact with the columnar epithelium, this, like the pavement epithelium of the tonsillar crypts and lingual tonsils, is filled with leukocytes. Also, elsewhere, in almost the entire intestinal canal, we occasionally find in

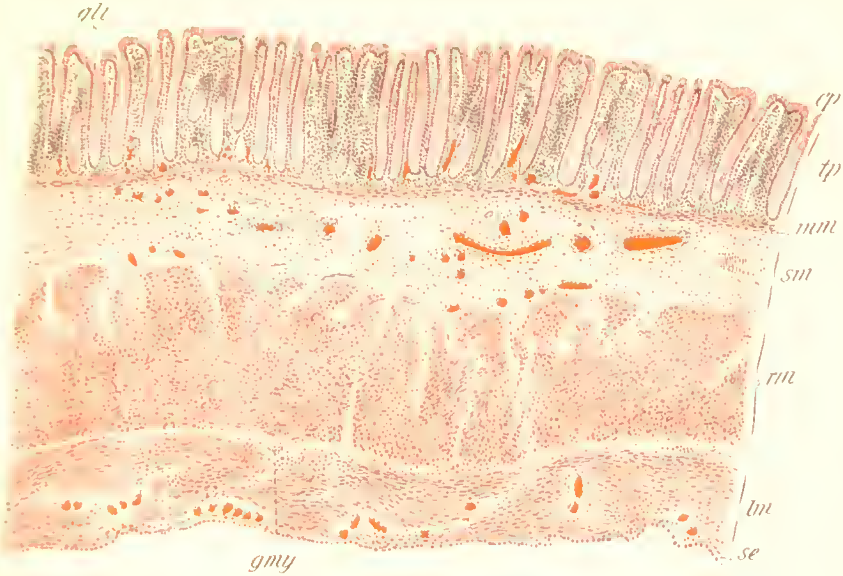

Fig. 1.

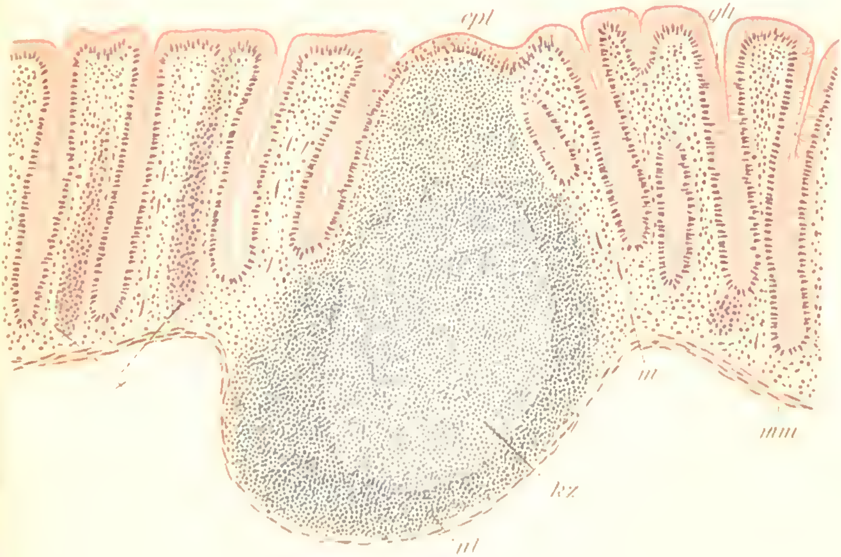

Fig. 2.

the columnar epithelium leukocytes arising from the diffuse adenoid tissue of the mucous membrane (see Plate 2, Fig. 3). The leukocytes wander through the epithelium of the vermiform appendix in great numbers, and often fill its narrow lumen.

THE BLOOD- AND LYMPH-VESSELS AND NERVES OF THE STOMACH AND INTESTINES.

The vessels and nerves are very similarly arranged in the stomach and intestine. The *arteries* in the mesentery which enter the intestine lie first in the subserous tissue and give off branches to the muscularis, then form in the submucosa a network from which branches arise which supply the muscular coat and mucous membrane. Here we find the capillary networks around the glands as well as on the surface of the mucous membrane; in the small intestine, a small artery also goes to each villus, passing up its center and breaking up into a capillary network, the blood from which is collected into a small vein. The capillaries of the villi lie immediately under the epithelium. The venous radicles, especially of the stomach and large intestine, are superficial. They arise from the capillaries, which are relatively large, and form a superficial network in the mucous membrane; in the stomach this is situated in the region of the necks of the glands, therefore below the base of the crypts.

The *lymph-vessels* begin in the small intestine, as the axial chyle vessels of the villi, while in the stomach and large intestine they begin as lymph capillaries between the glands; especially large capillaries surround the solitary lymph follicles, as well as the Peyer's patches. In the submucosa and between the two muscle layers, the lymph-vessels form networks. Large trunks run in the subserous tissue to the mesentery.

The *nerves* of the stomach and intestine arise mainly from the sympathetic, though certain medullated cerebro-

PLATE 39.—INTESTINAL EPITHELIUM, GOBLET-CELLS.

FIG. 1.—**Portion of a Longitudinal Section through the Villi of the Human Small Intestine.** × 325.

After a preparation of Professor Stöhr, Würzburg. It was taken from a man who had been executed.

The figure shows the structure of the intestinal villi, the diffuse lymphoid tissue of the tunica propria, the axial chyle-vessel (only part of which is met in the section), the columnar epithelium with cuticular border zone and goblet-cells in different stages of secretion.

Technic: Flemming's solution. Hematoxylin, saffranin, picric acid.

Reference letters: *ach*, Axial chyle-vessel of villus; *bm*, basal membrane of epithelium; bz_1, goblet-cells, beginning of secretion in the protoplasm; bz_2, goblet-cells filled with secretion; bz_3, goblet-cells after the secretion is evacuated; *c*, cuticular border of epithelium; *ep*, epithelium; *M*, evacuated mucus; *tp*, mucous membrane of villus.

FIG. 2.—**Longitudinal Section of Two Glands of Human Large Intestine.** × 160.

After a preparation of Professor Stöhr, Würzburg. This was taken from a man who had been executed.

The figure shows especially the distribution of the goblet-cells, which in the large intestine reach to the base of the glands.

Technic as in Fig. 1.

spinal nerves terminate therein. The majority of the nerve-fibers are non-medullated, and in the wall of the stomach and intestine form two *plexuses* with small ganglia at the nodal points. The larger plexus, the *plexus myentericus* or Auerbach's plexus, is situated between the circular and longitudinal muscular layers and has larger ganglia with multipolar nerve-cells and quite regularly polygonal to rhombic meshes. The neuraxes of the

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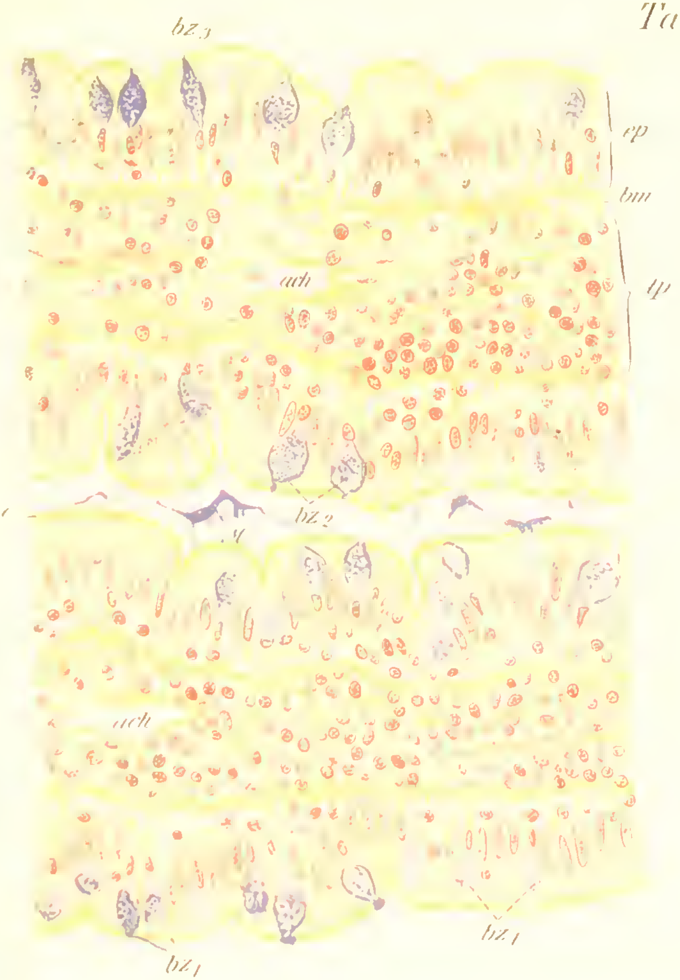
Fig. 48.—Part of a vertical section of the wall of the small intestine of the cat. × 20. The figure shows a cross-section of a Peyer's patch, the broader portion of which, containing the germ center, lies in the submucosa, while the apices of several nodes lie in the mucosa, forming a broad lymphoid villus. *lm*, Lymphoid portion of the mucous membrane; *nl*, lymph-nodes; *M*, muscularis; *sm*, submucosa; *vi*, intestinal villi.

Fig. 49.—Transverse section of an injected villus of an ape. × 500. The figure shows the cross-section of an intestinal villus, the epithelium of which shows a very distinct striated cuticular border. The blood-vessels are injected with Berlin blue. *ach*, Axial chyle-vessel, compressed; *cs*, cuticular border; *bz*, goblet-cell; *ep*, epithelium; *l*, leukocyte in epithelium.

Tab. 39.



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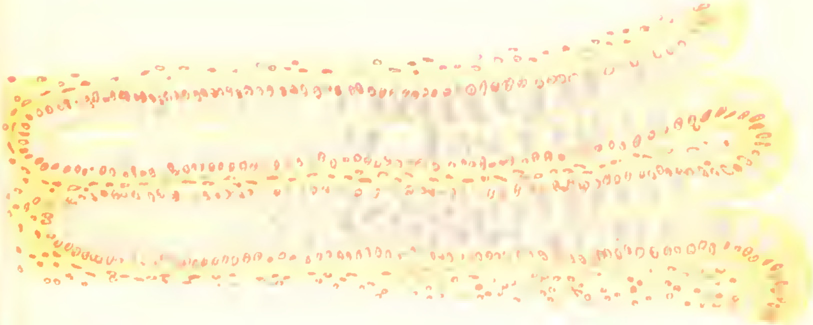

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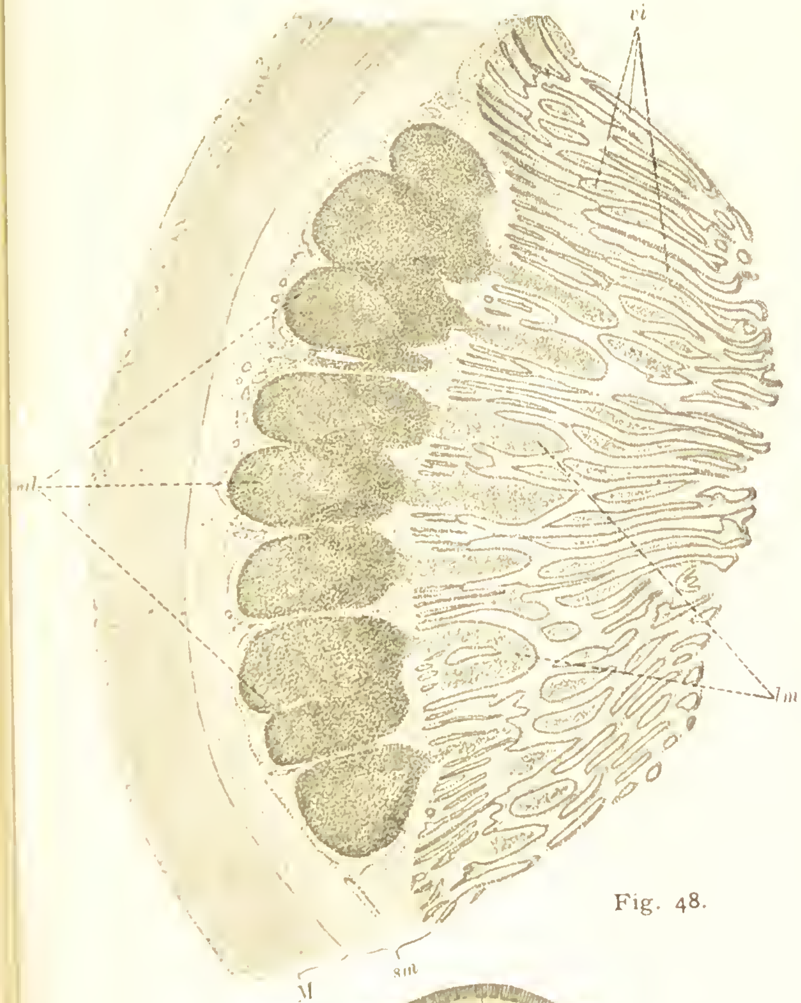

Fig. 48.

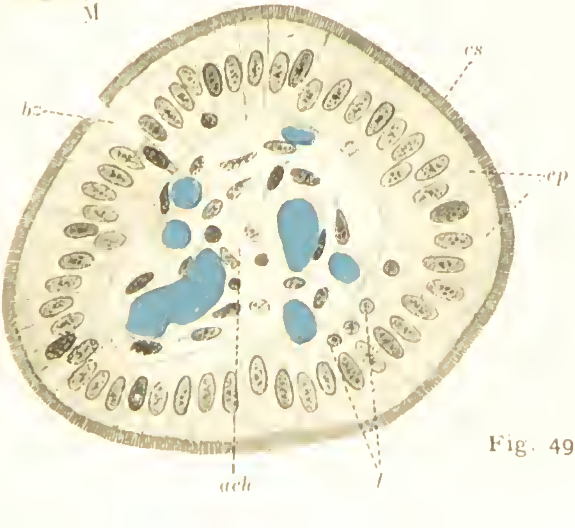

Fig. 49.

sympathetic neurones of the ganglia of this plexus supply the musculature.

The *plexus submucosus* or Meissner's plexus is much finer and less regular, its meshes being much smaller. The neuraxes of the ganglia of this plexus innervate the mucosa as well as the muscularis mucosæ, and the plexus therefore contains both motor and secretory fibers. Both plexuses begin in the esophagus and extend to the rectum.

White rami fibers terminate in end-baskets surrounding the cell-bodies of the sympathetic neurones situated in the ganglia of both plexuses. The larger medullated fibers are sensory cerebro-spinal fibers, the terminal branches of which end in the epithelium and probably also in the walls of the blood-vessels.

THE SALIVARY GLANDS.

Under this heading we shall consider the large salivary glands, the small glands of the mouth, and the pancreas. Certain of these glands secrete a serous secretion, rich in albumin, known as *albuminous or serous glands ;* others, a mucous secretion, *mucous glands ;* and certain glands form both serous and mucous secretion ; these are known as *mixed glands.* The appearance of the gland-cells which secrete the albuminous substance is essentially different from that of those which secrete mucus, and the structure of the mucus-secreting tubules—all these glands are tubular or tubulo-alveolar—differs from that of the *serous glands.* The tubules or alveoli of the serous glands are of small caliber, have a very small lumen, often so small that it can be seen only with difficulty. They are lined by a layer of cubical, distinctly granular cells, the nuclei of which lie about the middle of the cell. Between the serous cells, intercellular secretion capillaries are found (see page 36).

The *tubules* or alveoli of the mucous glands are large, their diameter being at least twice as great as that of the serous tubules ; their lumen is large, their cells clear,

PLATE 40.—VERMIFORM APPENDIX.

Transverse Section of the Human Vermiform Appendix. × 20.

The preparation was secured by means of an operation.

The figure shows the numerous solitary lymph follicles of the vermiform appendix and the few glands; in the lumen many leukocytes are seen; the musculature is very poorly developed.

Technic: Zenker's solution. Hematoxylin-eosin.

Reference letters: *e*, Epithelium; *F*, adipose tissue of submucosa; *L*, lumen; *M*, musculature; *al*, lymphatic nodules.

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with the nuclei pressed against the wall and often flattened. When filled with secretion, these cells are large, clear, vesicular structures and stain readily with those dyes which stain mucus. After the evacuation of their secretion, they stain more deeply in the general stains and appear darker in fresh preparations, but still differ from the cells of the serous glands. Secretion capillaries are lacking.

Tubules which contain only mucous cells are rare; tubules containing only serous cells are found in serous glands; in certain glands—the majority of the so-called mucous glands—the tubules contain both mucous and serous cells.

As has been stated, the salivary glands may be divided into serous glands, pure mucous glands, and glands having

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PLATE 41.—NERVE PLEXUS OF INTESTINE.

FIG. 1.—**Surface Preparation of the Myenteric Plexus of the Small Intestine of the Guinea-pig.** × 30.

The figure gives a general view of the distribution of the small ganglia of the plexus, their connections and principal branches.

Technic: Dilute acetic acid. Gold chlorid, formic acid.

Reference letters: *M*, Musculature of intestine (one muscle layer has been removed); *G*, ganglion, the darker spots are ganglion-cells.

FIG. 2.—**Portion of the Submucous Plexus of the Small Intestine of the Rabbit.** × 80.

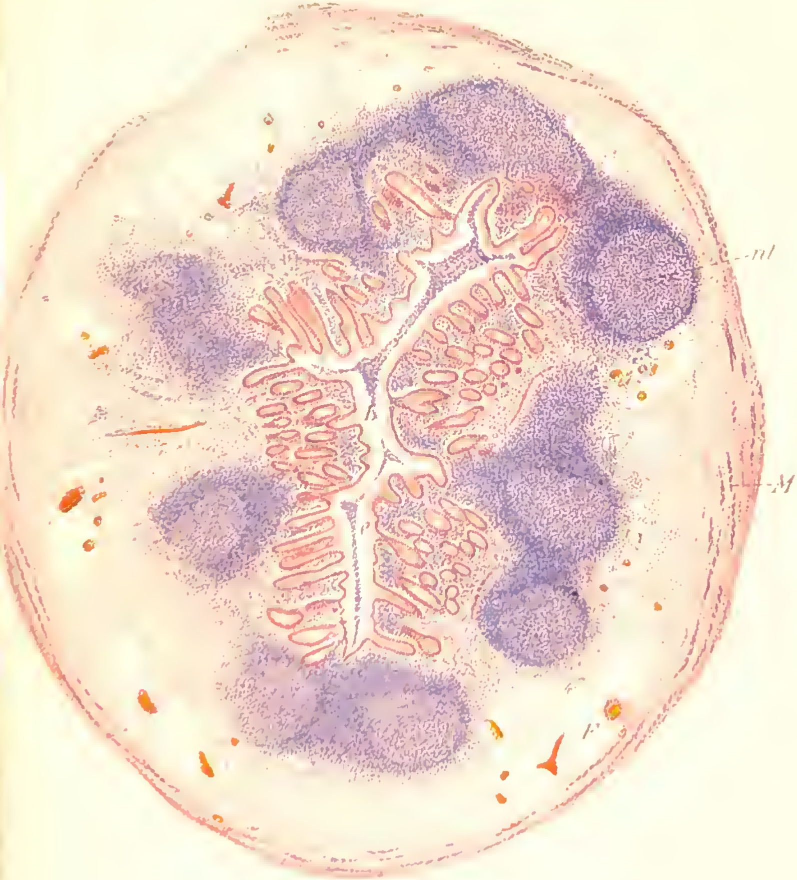
Only the plexus is represented.

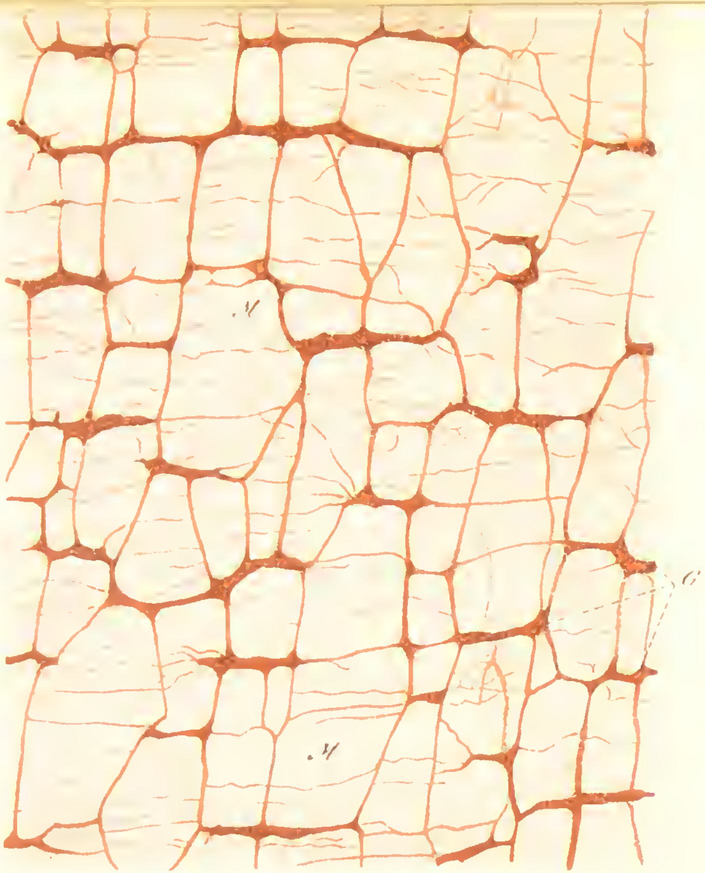
The figure shows the relation of the ganglia and the branches of the plexus.

Technic as in Fig. 1.

Reference letter: *g*, Ganglia.

Tab. 40.





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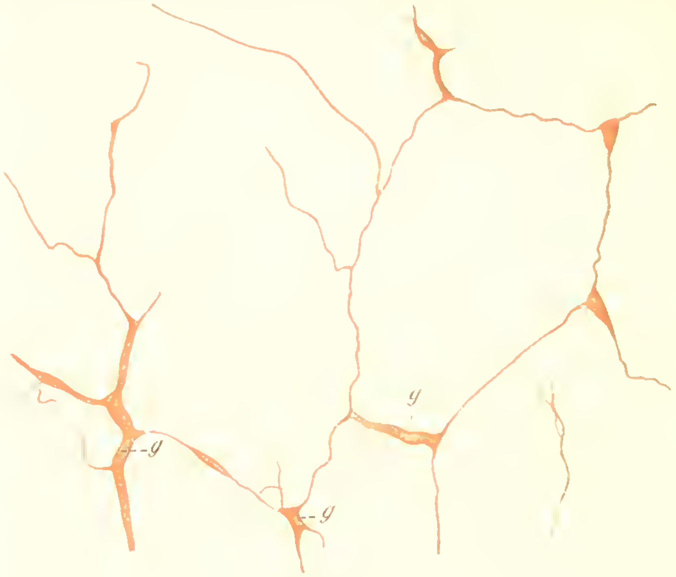

Fig. 2.

both serous and mucous secretion, namely the mixed glands. The latter are again divided into two subclasses: glands with tubules which contain both serous and mucous cells, and glands some of the tubules of which contain only serous cells while others contain either only mucous cells or both mucous and serous cells. The purely serous glands are the parotid, the small glands in the region of the circumvallate papillæ of the tongue and the pancreas. The purely mucous glands are the small glands at the root of the tongue and in the region of the lingual and pharyngeal tonsils and the palatal glands.[1]

Mixed glands of the first subdivision are the sublingual glands and all other smaller glands of the mouth, as well as the labial and buccal glands, glands of Nuhn, and others. The submaxillary is the only mixed gland of the second subdivision.

We will begin our more detailed consideration with the four *large salivary glands*, the parotid, the submaxillary, the sublingual, and the pancreas. They are all lobar, compound tubular or tubulo-alveolar glands, and are composed of many duct systems. The *parotid* has short tubular, markedly convoluted terminal alveoli, which have a very narrow lumen and only *serous* cells. The transition into the excretory duct system is made by long, very narrow *intermediary tubules*, lined by much flattened cells. Either singly or united, the intermediary ducts pass over into the *secretory* or *salivary ducts* (see Fig. 50), which are characterized by an epithelium of low columnar form, distinctly striated on the basal side. The salivary ducts then continue into larger portions of the duct system, which show no basal striation of the cells and possess two layers of epithelial cells as we approach the primary branches of the main excretory ducts. Of these two layers of cells, the cells of the lower layer are pyramidal and of the upper, columnar. In the *submaxillary gland*, the

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[1] Purely mucous glands also occur in other portions of the digestive tract, in the respiratory tract, genital organs, etc.

PLATE 42.—SALIVARY GLANDS.

FIG. 1.—**Portion of Section of the Human Sublingual Gland.** × 40.

The preparation was taken from a man who had been executed.

The figure shows the boundaries of two lobes of the gland, with a larger excretory duct and the adjacent gland tissue.

Technic: Zenker's solution. Hematoxylin-eosin.

Reference letters: *bdg*, Interlobular connective tissue with blood-vessels; Ds_1, larger excretory duct; Ds_2, smaller portion of the duct system (secretory tubes); *mu*, mucous alveoli as shown by reaction to stain; *v*, veins.[1]

FIG. 2.—**Portion of a Transverse Section of the Human Sublingual Gland.** × 90.

The preparation was taken from a man who had been executed.

The figure shows a number of gland tubules, some cut longitudinally, some transversely, and others tangentially. The distribution of the serous and mucous cells of the tubules is to be seen. (In certain regions the section passes through only serous cells and might therefore be confused with purely serous tubules.)

Technic: Absolute alcohol. Hematoxylin.

Reference letters: *b*, Interstitial connective tissue rich in lymph-cells; *hm*, demilune; *sr*, secretory tubule; *tm*, mixed-gland tubule in longitudinal section.

majority of the tubules are like those of the parotid, containing only serous cells. In addition to these there is a small number of long, much convoluted, large mucous tubules, which, however, especially at the blind ends, contain small groups of serous cells; these are known as the demilunes of Heidenhain or the crescents of Gianuzzi, so called because the serous cells are often arranged on the mucous cells in the shape of a ridge, and in cross-section give the appearance of a demilune. Such a demilune in the submaxillary is often formed by a single cell.

The duct system of the submaxillary is very similar to that of the parotid; only the intermediary duct is very much shorter. The salivary ducts show areas with dis-

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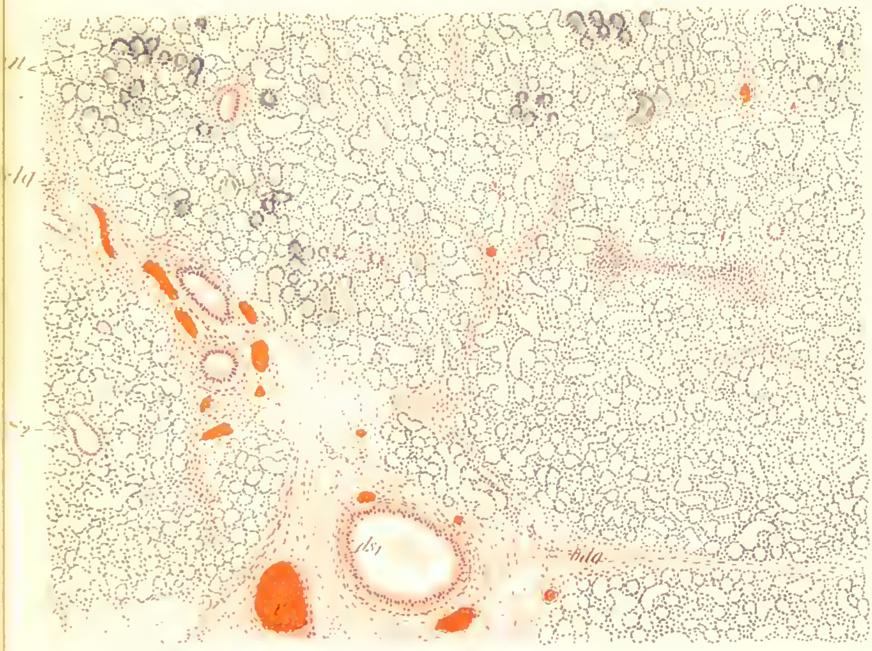
Reference letters for Figs. 50-53: a_1, Large branch of the main excretory duct; a_2, smaller branches of the same; *hm*, demilune; *s*, intermediary duct; *sr*, salivary ducts; *tm*, mixed tubules; *ts*, serous tubules; *t*, tubules or alveoli. (The serous cells are dark, the mucous clear.)

[1] In one vein, the blood in printing has become spotted.

Tab. 42.



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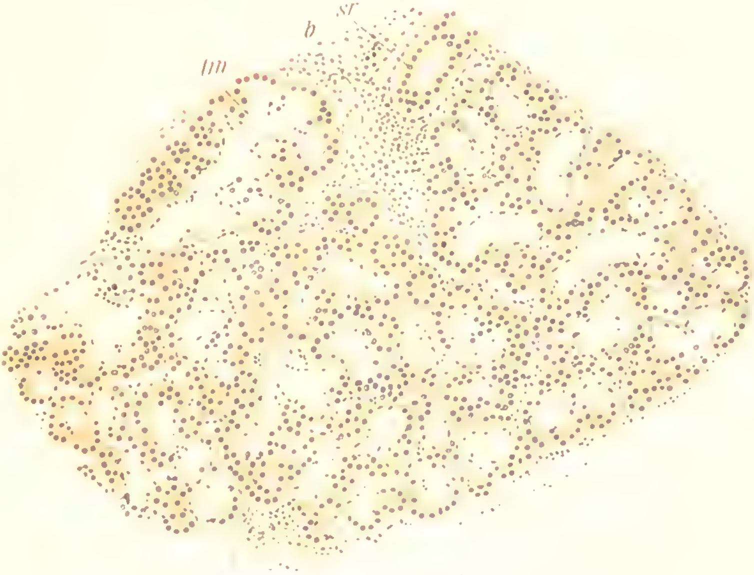

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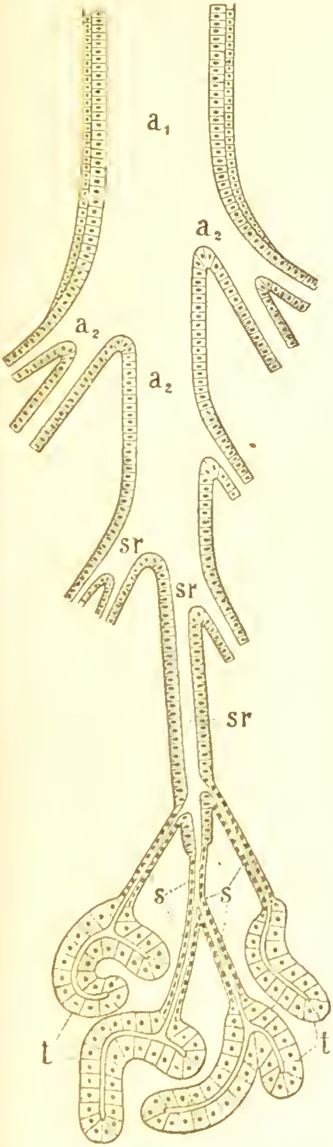

Fig. 50.—Diagrammatic representation of parotid gland.

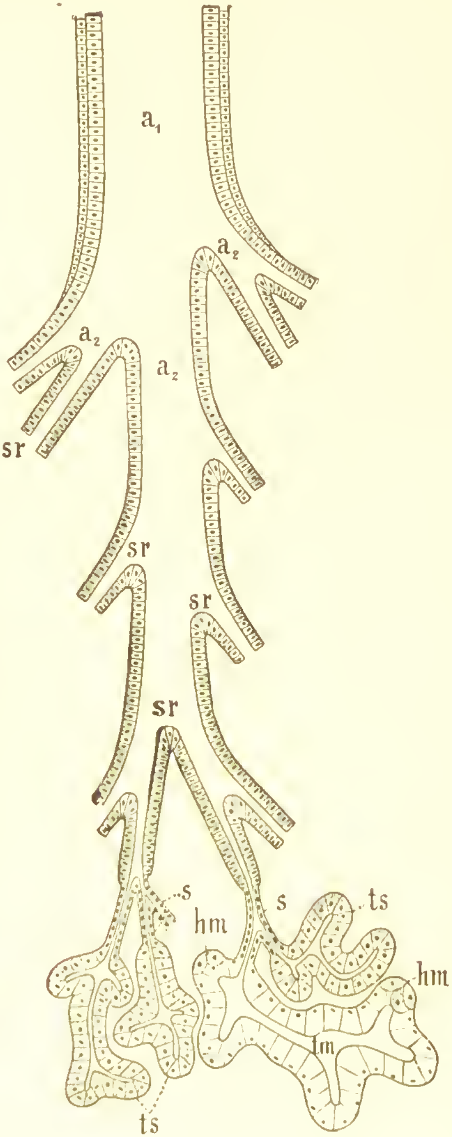

Fig. 51.—Diagrammatic representation of submaxillary gland.

(For explanation of lettering, see page 156.)

PLATE 43.—SALIVARY GLANDS.

FIG. 1.—**Portion of the Cross-section of the Human Submaxillary Gland.** × 150.

The preparation was taken from a man who had been executed.

The figure shows the glands composed of two kinds of tubules—purely serous and mixed. Moreover, intermediary ducts and salivary ducts with striated epithelium are seen.

Technic: Absolute alcohol. Hematoxylin-eosin.

Reference letters: *Hm*, Demilune; *L*, lumen of tubule; *sch*, intermediary duct; *sr*, salivary duct; *tm*, mixed tubules lined with mucous cells and having serous cells in the demilunes; *ts*, serous tubules.

FIG. 2.—**Small Area of a Relatively Thin Cross-section of the Human Parotid.** × 280.

The preparation was taken from a man who had been executed.

The figure shows cross-sections of a number of purely serous tubules only one of which shows a distinct lumen. The relation of the intermediary duct to the tubules and its transition to the salivary ducts is shown.

Technic: Absolute alcohol. Hematoxylin-eosin.

Reference letters: *l*, Lumen of the tubule; *sch*, intermediary duct; *sr*, salivary duct; *t*, tubules.

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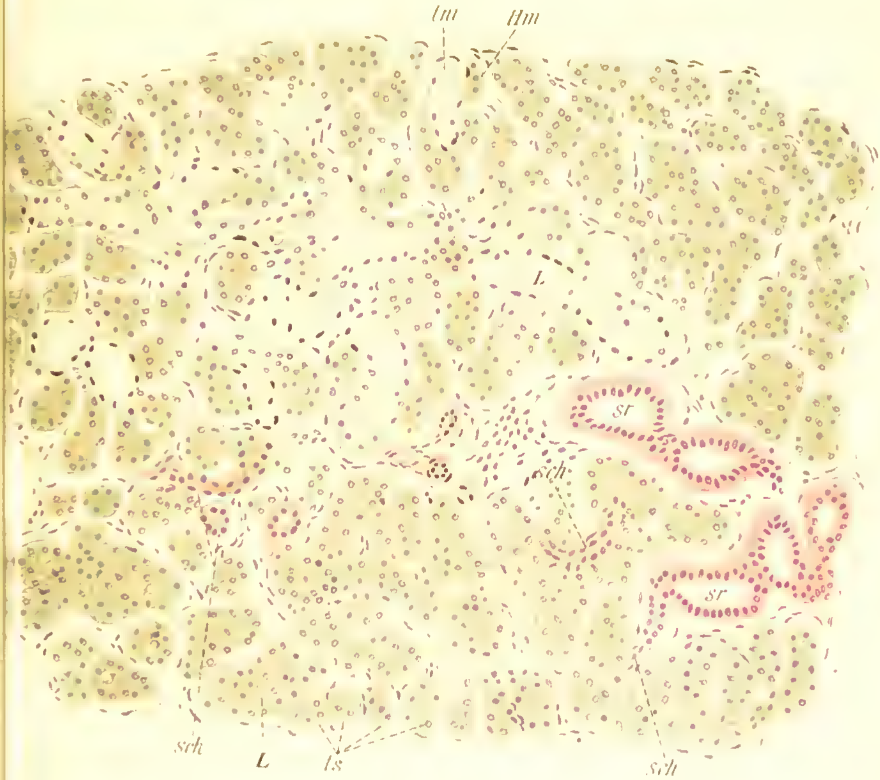
tinct basal striation; the main excretory duct has two layers of columnar epithelium, and outside of this, longitudinal muscle.

The *sublingual* contains only *mixed* tubules. All the tubules of the gland are therefore of similar structure and similar to the mucous tubules of the submaxillary; the demilunes are, however, much larger,—that is, the serous cells are much more abundant,—and often line the whole extent of the lumen. It may therefore happen that cross-sections of tubules of the sublingual are obtained, which are composed only of serous cells and resemble very closely the cross-sections of serous tubules. The duct system of the sublingual differs from that of the parotid and submaxillary in that the intermediary ducts are entirely lacking. The tubules pass directly into salivary ducts, the basal striation of whose cells is quite indistinct.

In the *pancreas* the secreting tubules are relatively short, often thickened at the ends; and are in the main similar to those of the parotid, for they possess only *serous* cells. The cells show, especially in the state of hunger, so-called

Tab. 43.



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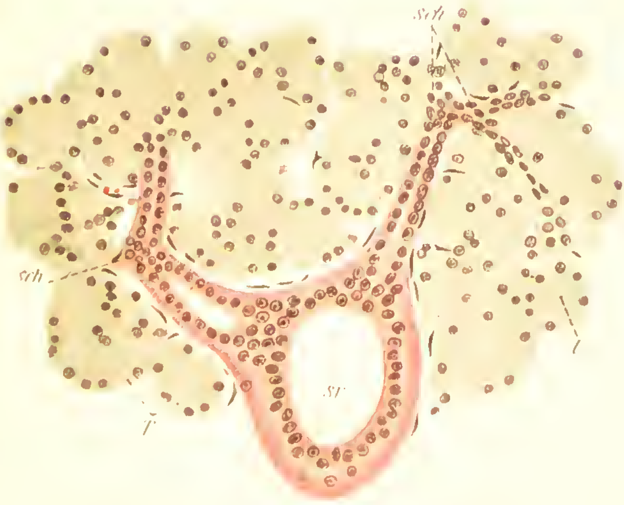

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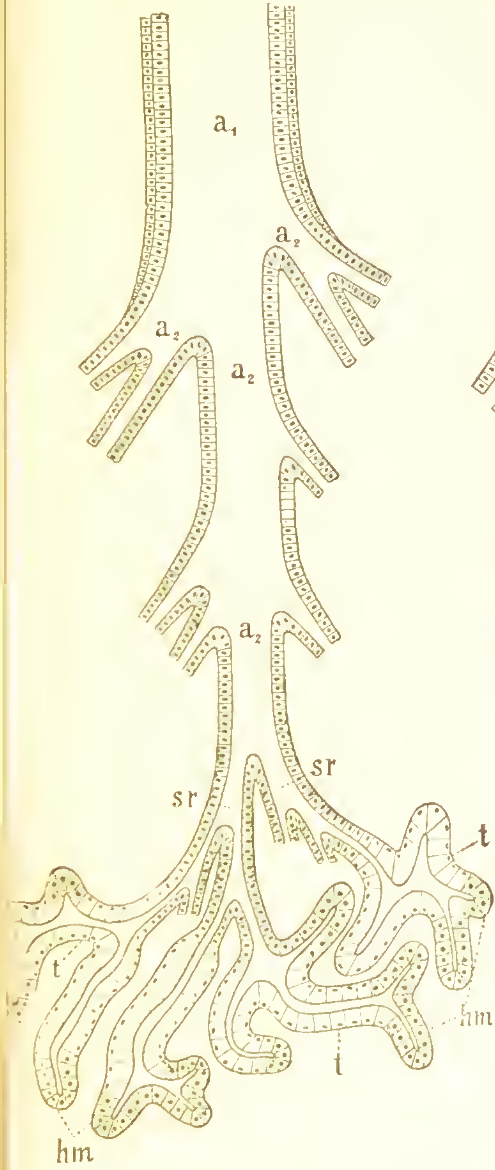

Fig. 52.—Diagrammatic representation of the sublingual gland.

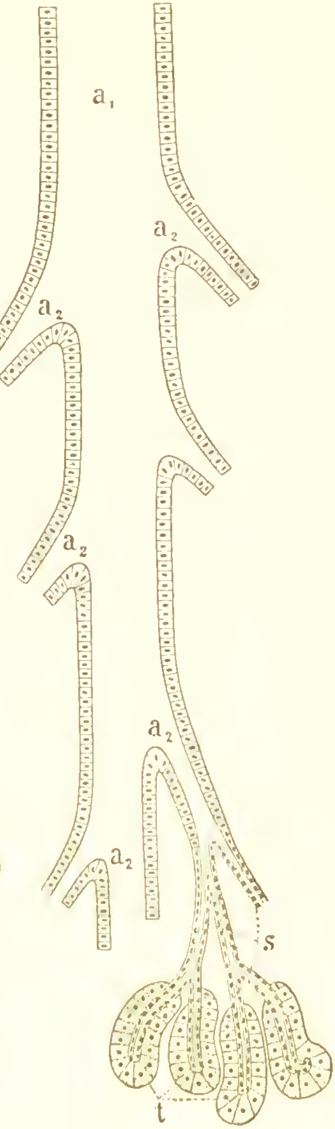

Fig. 53. —Diagrammatic representation of the pancreas.

(For explanation of lettering, see page 156.)

PLATE 44.—PANCREAS.

FIG. 1.—**Portion of a Cross-section of the Human Pancreas.** × 100.

The preparation was taken from fresh human tissue, fixed two and one half hours after death.

The figure gives a general view of the structure of the gland.

Technic: Zenker's solution. Hematoxylin-eosin.

Reference letters: *d*, Branch of the pancreatic duct; *sch*, intermediary duct; *ts*, cross-section of gland tubules.

FIG. 2.—**Small Portion of Fig. 1 from the Human Pancreas.** × 420.

The figure shows the cross-section of the intermediary duct and of some of the tubules connected with it. The relation of the centro-acinar cells to the cells of the intermediary duct is shown.

Technic as in Fig. 1.

Reference letters: *caz*, Centro-acinar cells; *drz*, gland-cells; *scht*, intermediary duct.

FIG. 3.—**Cross-section of Pancreatic Tubule.**

(From the same pancreas as Figs. 1 and 2.)

The figure shows the zymogen granules of the inner portion of the gland-cells.

Technic: Potassium chromate-formalin. Hematoxylin-eosin.

Reference letters: *caz*, Centro-acinar cells; *Zg*, zymogen granules.

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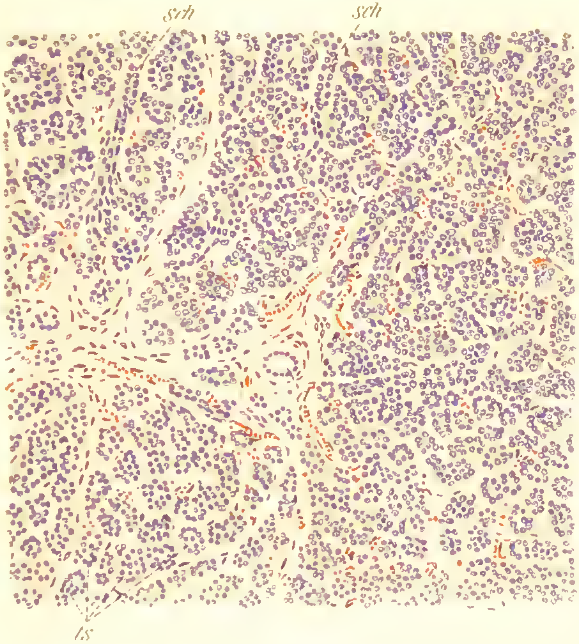
zymogen granules on the side toward the lumen. It is difficult to observe a lumen in the secreting tubules of the pancreas, since this is generally filled with flattened cells known as *centro-acinar cells*, which are regarded as a continuation of the flattened cells lining the *long intermediary duct* of the pancreas into the lumen of the secreting tubules. Salivary ducts are entirely lacking in the pancreas. The intermediary ducts pass directly into the branches of the main excretory duct, the pancreatic duct. The latter has cubic to columnar, occasionally almost flat epithelium, which is always in a single layer. Besides the tubular system above described, the pancreas contains certain structures known as the islands or *areas of Langerhans*. The meaning of these structures is still obscure, although it is generally believed that they form an internal secretion. They are composed of trabeculæ and septa of epithelial cells which neither form tubules nor connect with the excretory ducts by means of intermediary ducts, but are surrounded by dense capillary networks.



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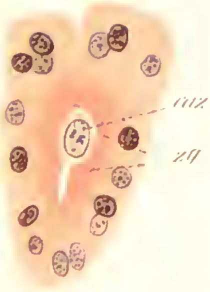

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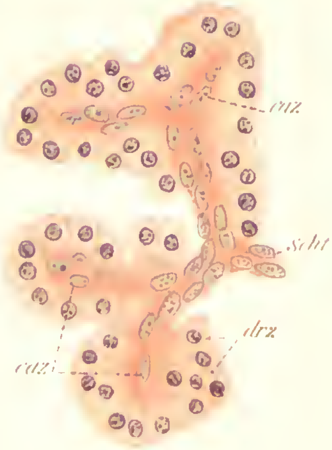

Fig. 3.

The *smaller glands of the mouth* usually consist of but one duct system. The single excretory duct is lined by a columnar epithelium, usually in many layers and occasionally ciliated. Their tubules are sometimes mucous, sometimes serous, and sometimes mixed (see page 153).

The salivary glands are rich in blood-vessels; numerous capillaries surround the tubules. In the interstitial connective tissue are found the neuraxes of sympathetic neurones, the branches of which probably penetrate the membrana propria and end free between the cells of the gland. The interstitial connective tissue of the sublingual is rich in lymph-cells, collections of which occur, appearing like solitary follicles, but having no germ centers.

THE LIVER.

The *liver* is a large compound tubular gland with anastomosing tubules. This condition can, however, be recognized only with difficulty in the fully developed human gland, as the original character of the independent tubules has been almost lost. There is also an intimate relation to the vascular system which dominates the arrangement of the former tubules. In this account of the structure of the liver we will give first a purely descriptive consideration of its structure, and in closing will attempt an elucidation of the tubular character of the organ.

The liver is surrounded by a connective-tissue capsule, known as the *fibrous capsule* or capsule of Glisson, which, at the hilus of the liver, extends into the organ with the blood-vessels. In many animals—for instance in the pig—each liver lobule, the anatomic unit of the liver, is surrounded by connective tissue from Glisson's capsule. In man the connective tissue of the liver is not so well developed and only for a short distance does it form the boundaries of adjacent lobules. The *liver lobules* are nearly cylindric structures. They consist of anastomosing trabeculæ of liver-cells, which show a distinctly radial

PLATE 45.—LIVER.

FIG. 1.—Portion of a Transverse Section of the Human Liver. × 35.

The preparation was taken from a man who had been executed.

The figure shows a number of liver lobules in cross-section, which are relatively well separated from each other.

Technic: Zenker's solution. Hematoxylin-eosin.

Reference letters: *cf*, Interlobular connective tissue of Glisson's capsule; *db*, bile-ducts; *vc*, intralobular or central vein; *vp*, branches of the portal vein, interlobular veins.

FIG. 2.—Portion of a Transverse Section of a Liver Lobule. × 280.

The figure shows the relation of the cords of liver-cells, their radial arrangement, and their anastomoses. Some cells have two nuclei.

Technic, etc., as in Fig. 1.

Reference letters: *c*, Capillaries; *f*, fat droplets in liver-cells.

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arrangement from the axis of the lobule. Each trabecula consists of liver-cells arranged in close rows. The cells are large (15–20 μ), irregular, polyhedral, have no distinct cell membrane, and are rich in protoplasm; they have relatively small nuclei (quite frequently there are two). In the fresh condition the liver-cells are distinctly turbid and granular (glycogen granules), and also contain fat in smaller and larger droplets and bile pigment. Contiguous liver-cells are in immediate contact and thus form *cords of cells* or trabeculæ, consisting of one or two rows of cells and anastomosing with neighboring cords without the intervention of the membrana propria.

The arrangement of these *cords of liver-cells* is dependent upon the arrangement of the blood-vessels, which should therefore be considered first. The afferent vessel of the liver is the *portal vein*. The hepatic artery supplies only the walls of the bile-ducts, the interlobular connective tissue, and the Glisson's capsule. Its capillaries pass directly into the branches of the portal vein. Terminal branches of the portal vein run as *venæ interlobulares* in the connective tissue between the lobules. Each lobule receives branches from several interlobular veins. The interlobular veins run in company with the small bile-ducts and with the arterial branches which

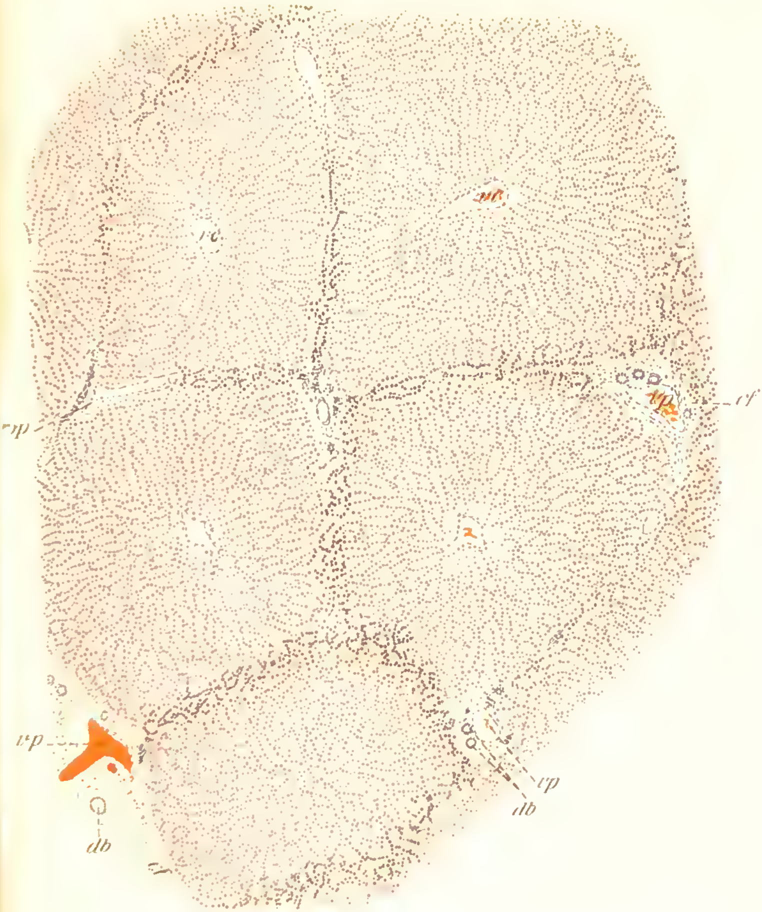
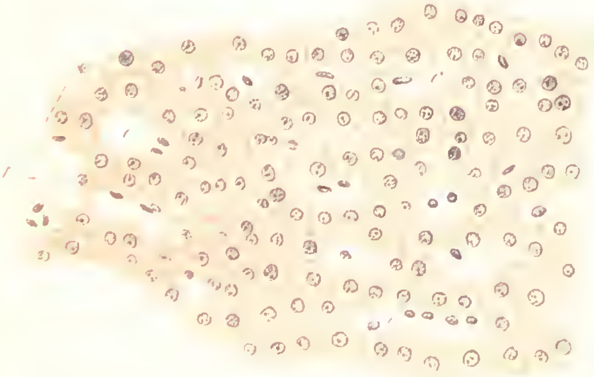


Fig. 1.



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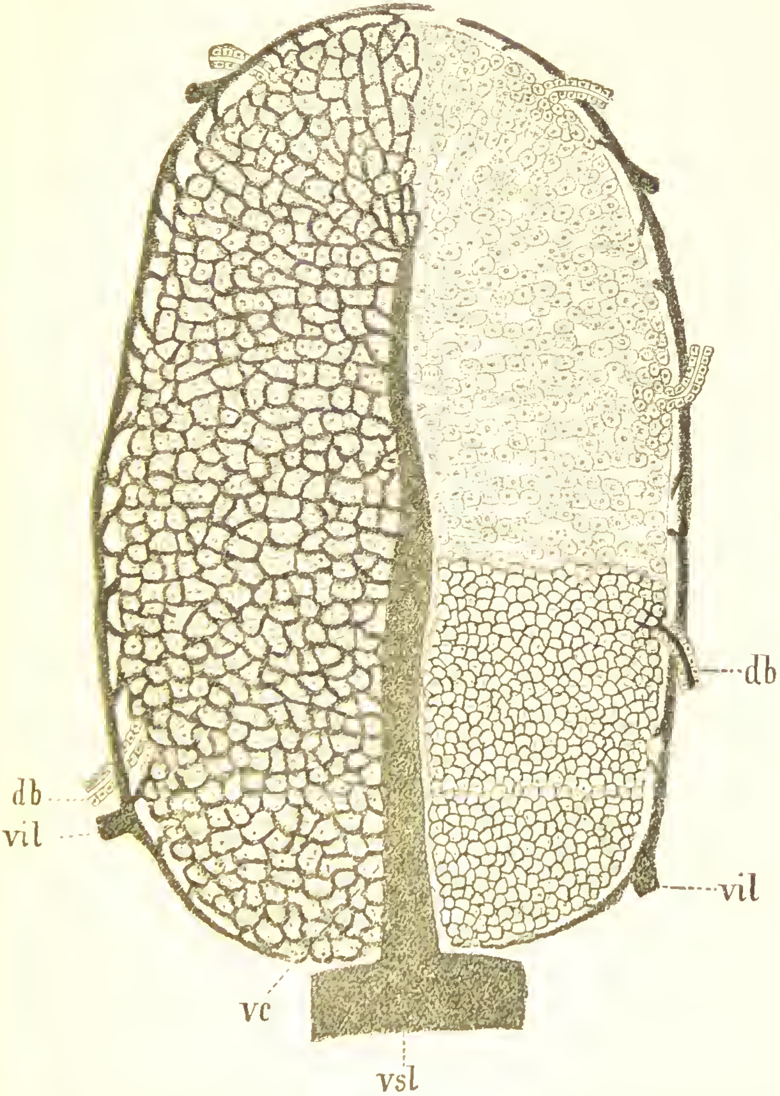

Fig. 54.—Diagrammatic representation of liver lobule. The figure shows a schematic longitudinal section; at the left the blood capillaries and at the right the bile capillaries are represented. *db*, Bile-ducts; *vc*, central or intralobular vein; *vil*, interlobular vein; *vsl*, sublobular vein.

PLATE 46.—LIVER.

Fig. 1.—**Portion of a Cross-section of the Liver of a Rabbit, Which Has Been Completely Injected.** × 45.

The figure shows a liver lobule in transverse section with injected vessels, together with adjoining parts of neighboring lobules. It gives a general view of the distribution of the blood-vessels in the liver (bile-ducts in the interlobular connective tissue).

Technic: Injection with Berlin blue gelatin. Müller's fluid. Borax-carmin.

Reference letters: *c*, Capillaries; *db*, bile-ducts; *vc*, central or intralobular vein; *vi*, interlobular veins.

Fig. 2.—**Portion of a Transverse Section of a Rabbit's Liver Treated by the Golgi Method.** × 300.

The figure shows the bile capillaries blackened by the Golgi method. These show many short, fine, blind processes which extend into the protoplasm of the liver-cells, short, intracellular secreting capillaries.

Technic: Potassium chromate-formalin. Silver impregnation according to Golgi method. Alum-carmin.

Reference letters: *c*, Blood capillaries; x, cell with many "secretory capillaries."

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supply the connective tissue and the walls of the bile-ducts.

From the periphery of the lobule the interlobular veins send toward the center of the lobule, through the network of cords of liver-cells, numerous large capillaries which frequently anastomose. In the axis of the lobule runs the terminal branch or the radicle of the efferent venous system of the liver, the *hepatic vein.* This is known as the *central* or *intralobular vein,* so called from its position in the liver lobule. It takes up the capillaries arising from the interlobular veins. The central or intralobular vein runs exactly in the axis of the lobule, beginning at its apex by the confluence of capillaries (see diagram) as a vein of the smallest caliber. During its course through the lobule it takes up capillaries from all sides, so that it increases in caliber and thus leaves the base of the lobule to open into the *sublobular vein,* a larger branch of the hepatic vein.

Each liver lobule is composed, therefore, of cords of liver-cells and the capillaries lying between them. The

Tab. 46.

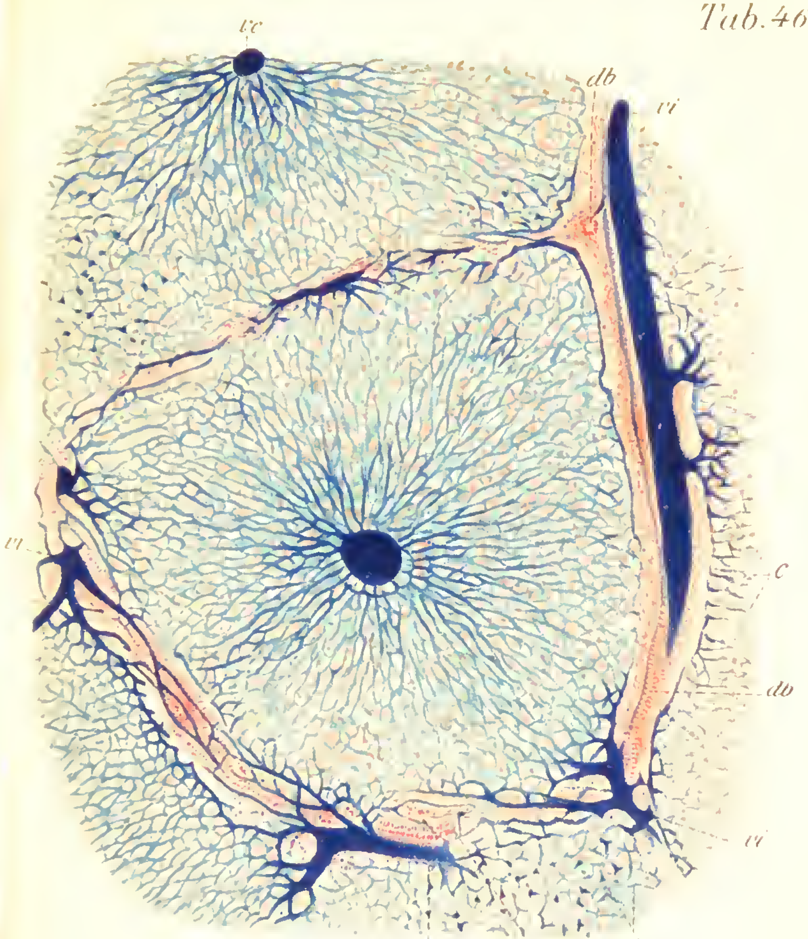

Fig. 1.

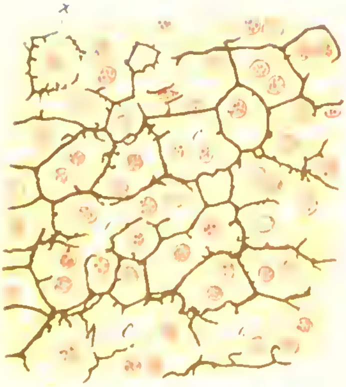

Fig. 2.

latter border directly on the liver-cells and usually run at their edges.

In addition to the liver-cells and capillaries, there are found in the liver lobule the following structures, which are made visible only by special methods: A connective-tissue framework within the liver lobule itself, which consists of very fine fibers forming very delicate networks around the capillaries, and known as "Gitterfasern," and of star-shaped cells, the so-called *stellate cells.* The nuclei of the latter lie between the liver-cells and are usually not to be distinguished from the nuclei of the capillaries. Reticular fibers, as well as stellate cells, appear only after the use of special staining methods.

Another constituent of the liver which is usually difficult to see is the *bile capillaries*, very fine ducts, lying between the liver-cells, without special walls and opening into the *bile-ducts.* The cubic epithelium of the latter represents the direct continuation of the liver-cells, since, at the periphery of the lobule, some cords of liver-cells have lower and smaller cells which pass over gradually into the epithelium of the bile-ducts (see diagram, Fig. 54). The bile capillaries may be regarded as intercellular secretion capillaries. They are formed by the two half grooves of neighboring cell-surfaces. They represent a very narrow and very fine network extending over the entire parenchyma of the liver, which has finer meshes than the blood vascular system. In general the bile capillaries run over the surface of the cells, while the blood capillaries run at the corners. The bile capillaries, for the most part, form anastomoses similar to those of the blood capillaries, but they also possess free intercellular and intracellular ends. The latter are found as short processes projecting into the cell protoplasm and terminating in nodular enlargements. These may probably be re-formed and also disappear again. The finer *bile-ducts* have a single layer of cubic epithelium; the larger ones, columnar epithelium with cuticular border. The epithelium of the gall-bladder is similar.

PLATE 47.—LIVER.

FIG. 1.—**Portion of a Transverse Section of the Injected Liver of a Rabbit (Blood Capillaries Red, Bile Capillaries Blue).** × 280.

Material from the Institute for Comparative Anatomy, Würzburg.

The figure gives a general view of the two capillary networks and their relation to the cords of liver-cells.

FIG. 2.—**More Highly Magnified Area of the Same Preparation from the Rabbit's Liver as Fig. 1.** × 500.

The figure shows blood capillaries, bile capillaries, and liver-cells in their mutual relation. Many of the liver-cells contain two nuclei.

Reference letters: *c*, Blood capillaries; *g*, bile capillaries; x, blind ends of bile capillaries.

The *nerves* of the liver are mostly non-medullated, the neuraxes of sympathetic neurones; they run with the arteries, veins, and bile-ducts, and terminate in the wall and epithelium of the bile-ducts, in the walls of the vessels, and probably also on the liver-cells.

We may imagine that two neighboring cords of liver-cells, with the bile capillaries lying between them, represent a former liver tubule without a membrana propria, the greatly reduced lumen of which is the bile capillary whose walls are formed by the two liver-cells. While the wall of the tubule of the liver in man, at least in the adult, is generally formed of but two cells, in many animals and also in the human embryo more than two cells bound the bile capillary, so that the liver tubule is quite similar to that of an ordinary tubular gland. Each row of liver-cells would at the same time belong to two or more tubules, as usually a bile capillary runs on each surface of the liver-cell. According to this conception each liver lobule consists originally of a number of tubules arranged radially to the axis of the lobule.

VI. THE URINARY ORGANS.

The *kidney* is a compound tubular gland, with the ureter as its excretory duct. It is surrounded by a connective-tissue capsule, the *tunica albuginea*.

Tab.47.

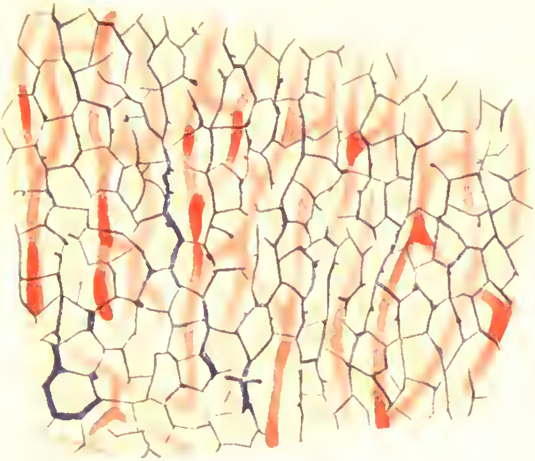

Fig 1.

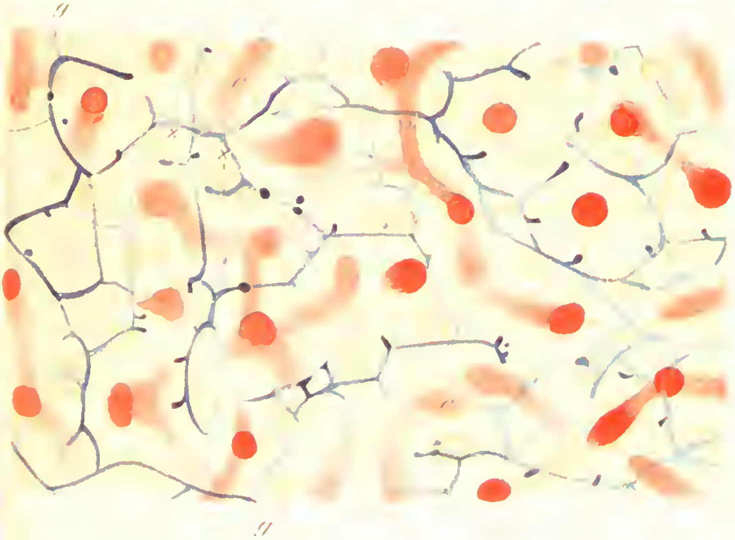

Fig 2.

The *uriniferous tubules* form the *parenchyma* of the kidney. The secreting portion of these tubules lies in the cortical substance, while those portions of the tubules which form part of the excretory system are found mainly in the medulla. The excretory ducts terminate at the apices of the medullary pyramids. The beginning of each uriniferous tubule is found in a spheric portion invaginated by a plexus of arterioles and capillaries. The plexus of arterioles and capillaries invaginating the beginning of each uriniferous tubule is known as a *glomerulus,* and this with the invaginated end of the tubule, known as *Bowman's capsule,* constitutes a *Malpighian corpuscle.* Bowman's capsule is a spheric, double-walled structure, invaginated by the glomerulus, so that its two layers are almost in apposition. The narrow interspace which remains is the beginning of the lumen of the uriniferous tubule. Both layers of Bowman's capsule, especially the invaginated "visceral" portion, have a very much flattened epithelium. The *uriniferous tubule* itself is a much convoluted tubule of considerable length and of characteristic structure in the various portions. The first portion, adjacent to the Bowman's capsule, is the *tubulus contortus.* Its lumen passes over directly into that of the capsule, its cubic epithelium changing quite abruptly into that of the capsular wall. The epithelium of the tubuli contorti shows generally very indistinct cell boundaries and a distinct striation of the basal portions of the cells; on the surface toward the lumen it presents a striated border resembling a cuticular formation similar to the rod-like border of the intestinal epithelium. This striated border is not always to be found and is said to be influenced by the functional condition of the kidney. The Malpighian corpuscles and the tubuli contorti always lie in the cortex of the kidney.

Following the contorted or convoluted portion of the uriniferous tubule is a segment which has the form of a loop, formed by two parallel limbs, and extending deep into the medullary substance; the depth to which it ex-

PLATE 48.—KIDNEY.

Portion of a Vertical Section of the Human Kidney. × 6.

The preparation was taken from a man who had been executed.

The figure gives a general view of the distribution of the cortical and medullary substance of the kidney. The section extends from the capsule into the papilla.

Technic: Müller's fluid. Hematoxylin-eosin.

Reference letters: *a*, Arteria arciformis; *cr*, Malpighian corpuscles; *pc*, convoluted tubules of cortex; *dp*, papillary ducts; *pr*, medullary rays of cortex; *sc*, cortex; *sm*, medulla; *tf*, tunica albuginea.

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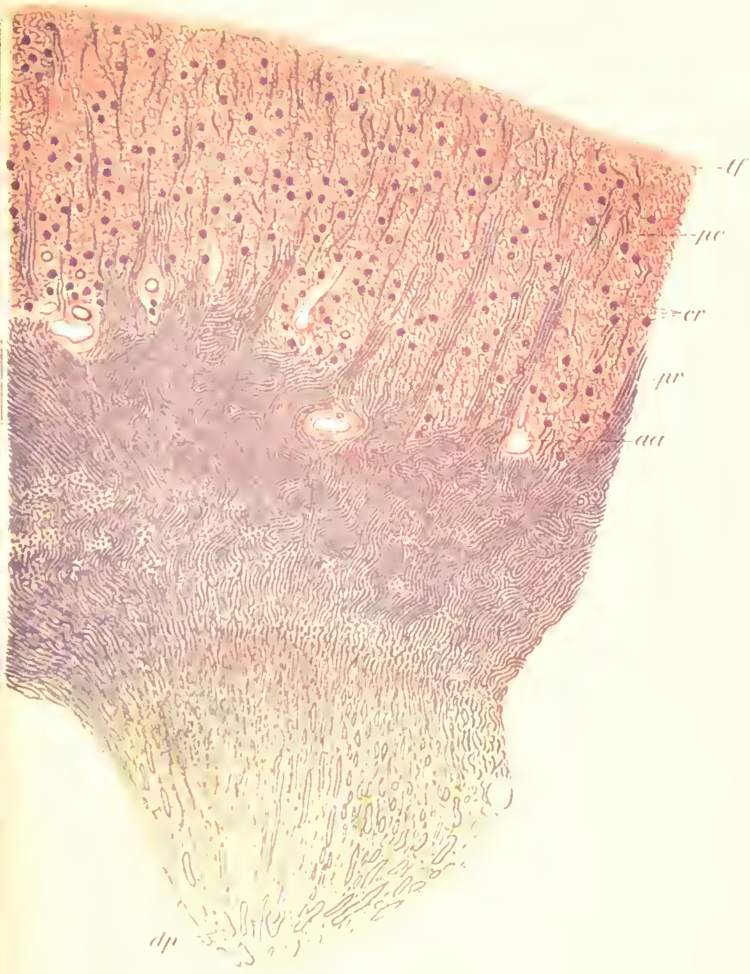
tends into the medullary substance depends upon the depth in the cortex of the Malpighian corpuscle of the respective tubule; this loop structure of the uriniferous tubule is known as *Henle's loop*. It consists of a thin, long descending limb, which has quite flat epithelium and a relatively large lumen, and a shorter, thicker ascending limb with considerably higher epithelium of flattened cubic shape resembling that of the convoluted tubules, but somewhat lower and with indistinct cell boundaries.

The ascending limb passes into the cortical substance and continues as a short, slightly convoluted portion of the tubule, the *intermediary portion*. It lies near the medullary rays of the cortex and always lies deeper than the convoluted tubule belonging to it. The epithelium of the intermediary portion is formed of non-striated columnar cells.

The intermediary portion is followed by the straight uriniferous tubule, which is situated in the medullary rays of the cortex of the kidney. The straight tubules or collecting tubules form the beginnings of the excretory duct system. Each collecting tubule takes up several uriniferous tubules, and in the medullary rays, and especially in the medulla, they unite at acute angles to form larger collecting tubules; and finally, with still greater increase of caliber, they form the *papillary duct* opening on the area cribrosa of the papilla. The *collecting tubes* have at first cubic epithelium; later it becomes columnar, and the papillary duct has tall columnar epithelium.

Tab. 48.



The entire uriniferous tube possesses a structureless membrana propria, which, however, is not equally distinct in all portions of the tube. Between the uriniferous tubules there is found a small amount of *interstitial con-*

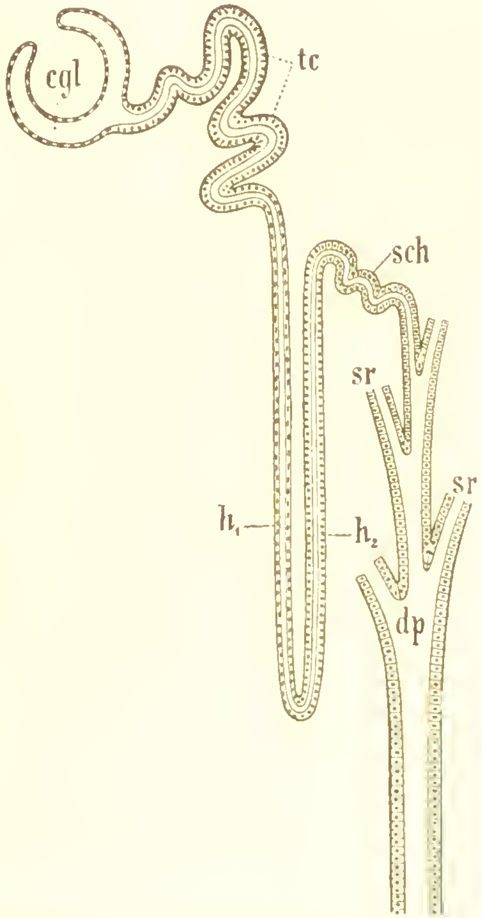


Fig. 55.—Diagrammatic representation of urinary tubule: *cgl*, Capsule of glomerulus; *dp*, papillary duct; h_1, narrow proximal limb of Henle's loop; h_2, wider distal limb of the loop; *sr*, collecting tube; *tc*, contorted or convoluted tubule; *sch*, intermediary portion.

PLATE 49.—KIDNEY.

FIG. 1.—**Portion of a Vertical Section of the Cortical Substance of the Human Kidney.** × 45.

The preparation was taken from a man who had been executed.

The figure shows the distribution of the straight and convoluted tubules as well as of the Malpighian corpuscles.

Technic: Zenker's solution. Hematoxylin-eosin.

Reference letters: *sc*, Convoluted tubules; *gl*, glomeruli; *sr*, medullary rays; *tf*, tunica fibrosa or albuginea; *ti*, interstitial tissue with blood-vessels.

FIG. 2.—**Small Portion of the Cortical Substance of the Human Kidney, Showing the Transition of a Convoluted Tubule into the Bowman's Capsule.** × 280.

The figure shows a glomerulus within its capsule. The flattened epithelium of the latter passes immediately over into the cubic epithelium of a convoluted tubule. In addition to this, we see transverse sections of the convoluted tubules with striated epithelium, without cell boundaries, and also sections of the intermediary tubules.

Technic, etc., as in Fig. 1.

Reference letters: *cgl*, Bowman's capsule; *gl*, glomerulus; *Sch*, intermediary portion; *tc*, convoluted tubules; *ti*, interstitial connective tissue; x, intermediary portion cut tangentially.

FIG. 3.—**Epithelium of the Convoluted Tubules of the Human Kidney, Showing Striated Border.** × 500.

The figure shows a portion of the epithelium of the convoluted tubule, which presents the striated border, but no basal striation.

Technic, etc., as in Fig. 1.

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nective tissue, containing the blood-vessels and nerves of the kidney.

The *blood-vessels* of the kidney are worthy of note. The *arteries* enter the kidney substance at the base of the pyramid, near the boundaries of the columns of Bertini. Here the main trunks of the renal artery branch into the *arteriæ arciformes*, arching at the boundaries of the cortical and medullary substance. From the convex side of the arch, which is turned toward the cortical substance, branches arise, the so-called *interlobular arteries*,[1] which ascend into the cortex, between the medullary rays toward the surface of the kidney, and give off the vasa afferentia for the glomeruli of the renal corpuscles. The *glomeruli*

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[1] So called because the portion of the urinary tubules belonging to one papillary duct is regarded as a renal lobule. The renal lobules are, however, not separated from each other.

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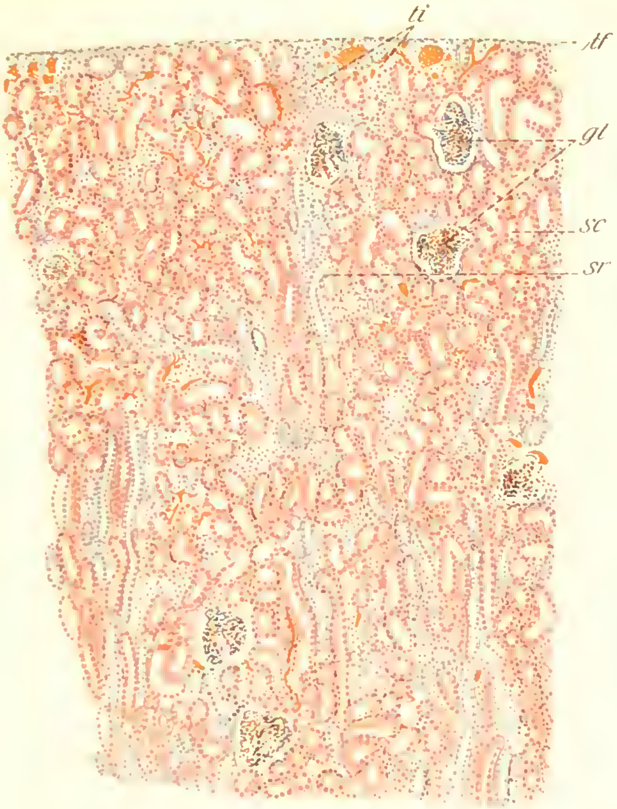
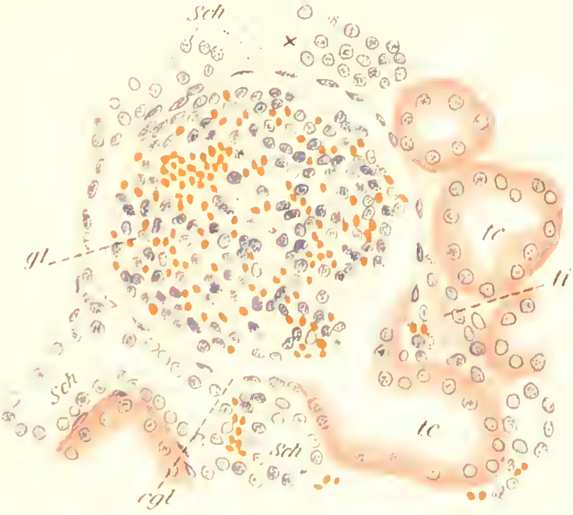


Fig. 1.



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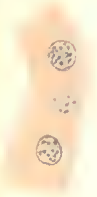

Fig. 3.

represent retia mirabilia, the efferent branches of the glomeruli carrying arterial blood. The glomeruli of the kidney are therefore inclosed in the arterial circle. The afferent vessel, vas afferens, as well as the smaller efferent vessel, the vas efferens, are arteries. The vascular windings of the glomerulus show the structure of capillaries, possessing a syncitial endothelium, but they are larger than ordinary capillaries. From the vasa efferentia of the glomeruli arise true capillaries, which are distributed in part to the convoluted tubules of the cortical substance and in part extend as very small straight arteries, the so-called arteriolæ rectæ, into the medullary substance. Cortical branches also arise from the terminal branches of the interlobular arteries.

From a number of capillaries and very small *veins*, the veins of the cortex of the kidney collect quite suddenly in the cortical substance just under the capsule to form the *venulæ stellatæ*, which serve as points of origin for the *interlobular veins;* these take up the capillary blood from the deeper portions of the cortex. They accompany the interlobular arteries and pass over into the *venæ arciformes*, which, in position and other conditions, correspond to the arteriæ arciformes.

While the cortex of the kidney is very rich in blood-vessels, the reverse is the case in the medullary portion of the kidney. As the large vessels of the kidney run at the boundary of the cortex and medulla, no large blood-vessels are contained in the medulla of the kidney. The arterial and venous trunks of the medullary portion of the kidney are characterized by a straight course parallel to the course of the tubules and are known as the arteriolæ and venæ rectæ. The capillaries form a long-meshed network. The arteries of the medullary substance are in part direct branches from the concavity of the arteria arciformis, partly vasa efferentia of the deeper glomeruli, and partly deep direct branches of the interlobular arteries. The venulæ rectæ open directly into the venæ arciformes.

PLATE 50.—KIDNEY.

FIG. 1.—**Transverse Section of the Medullary Substance of the Human Kidney.** × 150.

The preparation was taken from a man who had been executed.

The figure shows sections of large collecting tubules with columnar epithelium; smaller tubules with flattened cubic epithelium (descending limb of Henle's loop) and cross-sections of capillaries.

Technic: Müller's fluid. Hematoxylin-eosin.

Reference letters: *c*, Blood capillaries; Hs_1, ascending limb of Henle's loop; Hs_2, descending limb of Henle's loop; *tr*, collecting tubules.

FIG. 2.—**Portion of a Transverse Section of a Human Kidney Injected through the Arteries.** × 15.

The figure shows the boundaries of cortical and medullary substance, and the adjacent parts of both. It shows the principal relations of the renal arteries.

Technic: Injection with Berlin blue gelatin. Müller's fluid. Borax-carmin.

Reference letters: *ai*, Interlobular arteries; *ar*, arteriolæ rectæ; *gl*, glomeruli; *va*, vena arciformis.

Direct anastomoses between arteries and veins occur in the kidney.

The *lymph-vessels* of the kidney run in company with the arteries; likewise, the sympathetic *nerves* form plexuses for the blood-vessels and can be followed even to the glomeruli. Sympathetic nerve-fibers terminate also on the epithelium of the uriniferous tubules.

PLATE 51.—KIDNEY.

FIG. 1.—**Two Injected Glomeruli of the Human Kidney.** × 120.

Reference letters: *va*, Vas afferens; *ve*, vas efferens.

FIG. 2.—**Portion of a Cross-section through the Kidney of a Guinea-pig, Injected through the Vein.** × 15.

The figure shows the entire thickness of the cortical substance and the greater portion of the medullary substance. Only the veins and capillaries are injected, and not the arteries; hence not the glomeruli.

Technic: Injection with Berlin blue gelatin. Müller's fluid. Borax-carmin.

Reference letters: c_1, Capillaries of the cortex; c_2, capillaries of the medullary substance; *sc*, cortical substance; *sm*, medulla; *va*, vena arciformis; *vr*, venulæ rectæ; *vst*. venulæ stellatæ, partly passing into the venæ interlobulares.

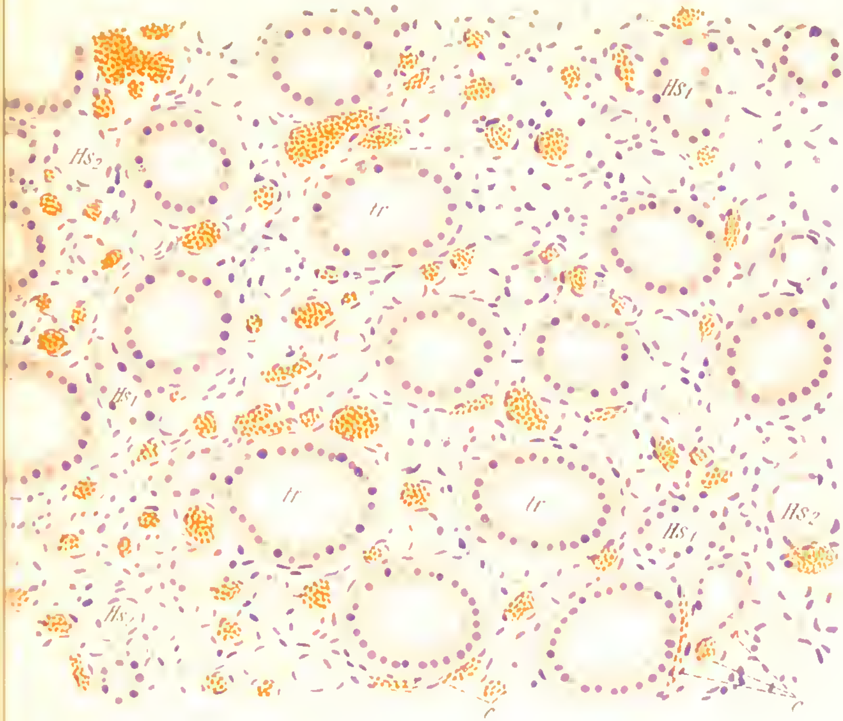

Fig. 1.

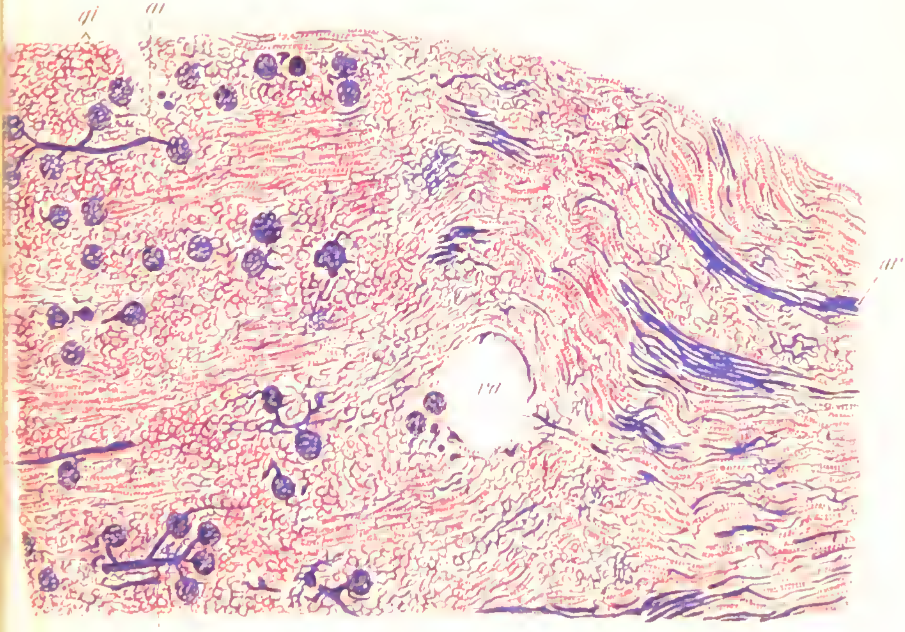

Fig. 2.

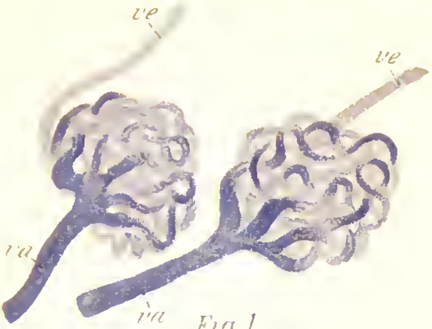

Fig. 1

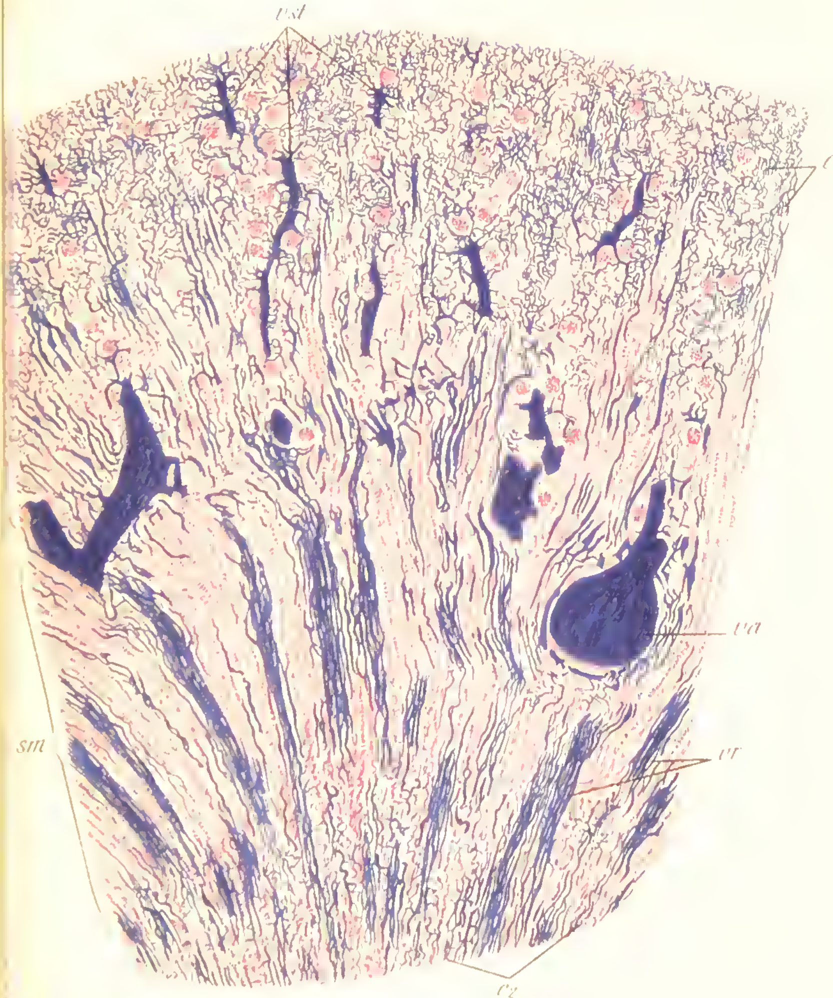

Fig. 2.

THE EFFERENT URINARY PASSAGES.

The efferent urinary passages include the *calices and pelvis of the kidney*, the *ureter*, the *bladder*, the *female urethra*, and the *beginning of the male urethra*. These are all lined with the same epithelium, the so-called *transitional epithelium* (see page 32).

The mucous membrane of the **ureter** and its radicles, which is much folded when empty, consists of a thin connective-tissue membrane containing elastic fibers, which passes without distinct boundaries into the submucosa. There are no glands and no muscularis mucosæ. The mucous membrane contains numerous lymph-cells, which occasionally form larger collections and are also met in the epithelium. The *musculature* of the ureter is characterized by scattered bundles of muscle separated by connective-tissue bundles. It is most fully developed in the lower portion of the duct. It consists there of inner longitudinal, middle circular, and outer longitudinal bundles. The latter are almost entirely lacking in the upper portion. The musculature is surrounded on the outside by a connective-tissue adventitia. The blood capillaries of the mucous membrane of the ureter are in direct contact with the epithelium, so that in the folds they seem to lie in the epithelium; they lie, however, in small folds of the mucosa practically composed of the capillaries.

The **bladder** is very similar in structure to the ureter. The epithelium of the two is the same. The mucous membrane of the bladder shows the same characteristics as that of the ureter; it not infrequently contains small lymph-nodes. The submucosa, also, is not well separated from the mucosa and contains adipose tissue occasionally. The bladder, as well as the ureter, contains no glands.

The *musculature* of the bladder is much more developed than that of the ureter, but it presents the same lamination, an inner and an outer longitudinal layer and a middle circular. The muscle layers, especially the inner

PLATE 52.—URETER, BLADDER.

FIG. 1.—**Transverse Section of the Wall of the Human Bladder.** × 15.

The preparation was taken from a man who had been executed.

The figure gives a general view of the structure of the bladder.

Technic: Zenker's solution. Hematoxylin-eosin.

Reference letters: *alm*, External longitudinal layer of muscle; *ep*, epithelium; *ilm*, inner longitudinal layer of muscle; *rm*, circular muscle layer; *sm*, submucosa; *ta*, tunica adventitia; *tp*, tunica propria.

FIG. 2.—**Transverse Section through the Human Ureter.** × 25.

The preparation was taken from a man who had been executed.

The figure gives a general view of the structure of the ureter.

Technic: Absolute alcohol. Hematoxylin-eosin.

Reference letters: *al*, External longitudinal layer of muscle; *ep*, epithelium; *ilm*, inner longitudinal layer of muscle; *L*, lumen; *rm*, circular muscle layer; *sm*, submucosa; *ta*, tunica adventitia; *tp*, tunica propria.

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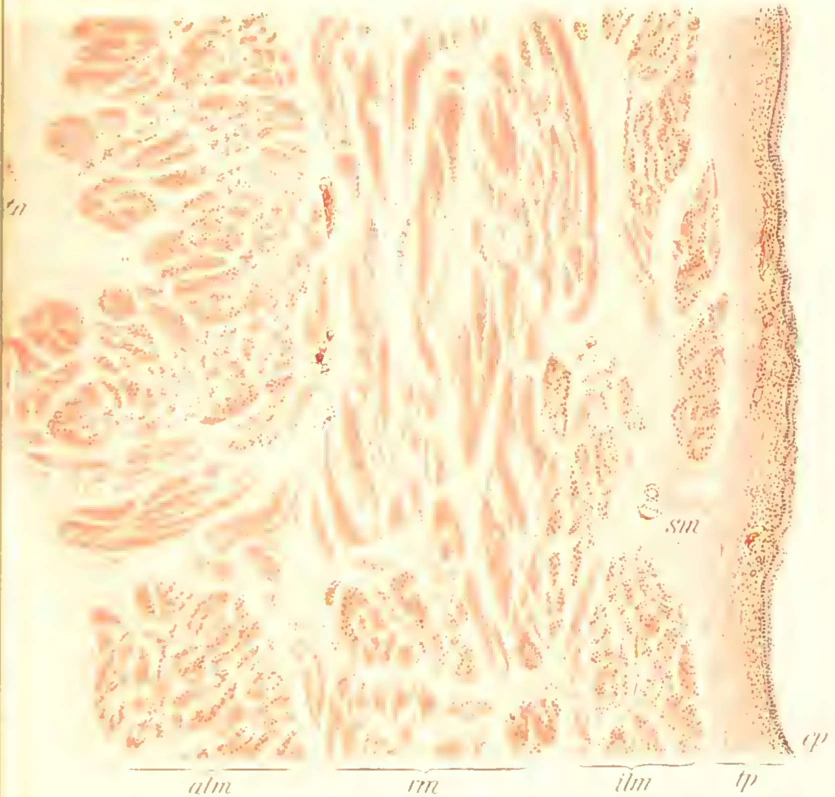
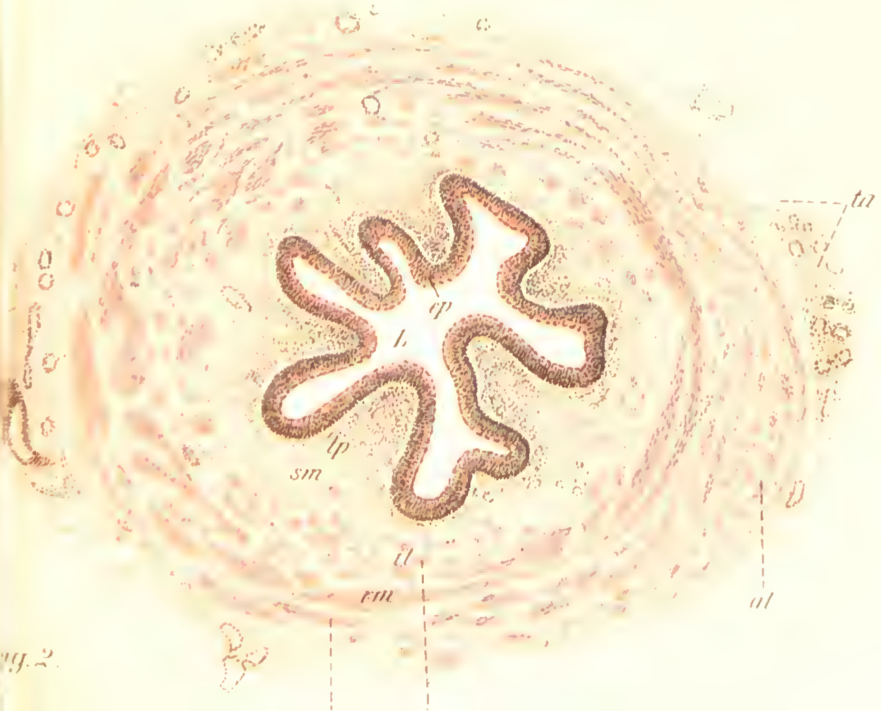
longitudinal layer, show distinct reticular arrangement of the fibers. The wall of the bladder of amphibia contains perfect networks of smooth muscle-fibers (see Fig. 2, Plate 58). The upper and posterior portions of the bladder have a serous covering of peritoneum.

There are said to be no lymph-vessels in the mucous membrane of the bladder; they occur in the musculature.

The outer portion of the **female urethra** is lined by stratified pavement epithelium, while the inner is lined by transitional epithelium. In the outermost portion of the female urethra are found *mucous glands.* The mucous membrane contains numerous veins, forming a dense network. The female urethra is surrounded by a well-developed muscle, which is arranged mostly in circular layers. The inner layer of this muscle, in which the fibers are arranged longitudinally, is permeated by the venous plexus of the mucosa.

For the male urethra see the male reproductive organs.





ig. 2.

VII. THE MALE REPRODUCTIVE ORGANS.

The **testis** is a compound tubular gland, with an anastomosing duct system, which is surrounded by a firm connective-tissue sheath, the *tunica albuginea.* On the posterior surface of the testis a wedge-shaped connective-tissue structure is found, known as the *mediastinum testis* or corpus Highmori, from which pass vascular connective-tissue trabeculæ, the septula testis, to the tunica albuginea. These bound the several pyramidal lobules of the testis, the *lobuli testis.* The lobules contain the greatly convoluted *tubuli seminiferi contorti*, the true parenchyma of the testis, between which strands of very loose connective tissue are found. In addition to the nerves and blood-vessels, the interstitial connective tissue of the lobule in man contains a varying number of large *plasma cells* with relatively small nuclei, which contain fat droplets, pigment, and crystalloids. In many animals these interstitial cells, also called interstitial testicular cells, are very well developed and scarcely less prominent than the parenchyma,—for instance in the testis of the boar,—which therefore appears brown in cross-section like the liver.

The *convoluted tubules of the testis* begin in the lobule in the neighborhood of the albuginea, partly in blind ends and partly branched reticularly. Toward the boundary of the mediastinum testis the tubules become less convoluted and finally straight, forming the *tubuli recti ;* these continue into the *rete testis* situated in the mediastinum. The latter represents the beginning of the excretory duct system.

The walls of the convoluted tubules consist of several nucleated layers, which have on their inner surface a stratified epithelium varying in appearance and structure according to the stage of spermatogenesis. For the same reason the size of the normally relatively large lumen varies.

PLATE 53.—TESTIS.

FIG. 1.—**Transverse Section of the Testis, Epididymis, and Vas Deferens of a Child.** × 10.

The figure represents the general picture of the testis and its adnexa.

Technic: Müller's fluid. Hematoxylin-eosin.

Reference letters: *bg*, Blood-vessels (especially veins of the plexus pampiniformis); *dd*, vas deferens; *Ep*, epididymis; *l*, lobules of testis; *m*, mediastinum testis; *rt*, rete testis; *s*, septula testis; *T*, testis; *ta*, tunica albuginea.

FIG. 2.—**Portion of a Transverse Section of a Lobule of the Human Testis.** × 60.

The preparation was taken from a man who had been executed.

The figure shows the cross-section of the convoluted seminiferous tubules and of the interstitial tissue of the testis.

Technic: Zenker's solution. Hematoxylin-eosin.

Reference letters: *tc*, Convoluted tubules; *ti*, interstitial tissue; *Zz*, interstitial cells.

During spermatogenesis the epithelium of the convoluted tubules is so arranged that the youngest generation of cells is nearest to the lumen, the oldest toward the wall of the canal. The secretion of the seminal tubules consists of the spermatozoa or spermatosomes, peculiar motile cells, consisting of three constituents—the body or head, the middle piece, and the tail.

Under higher magnification, other structural peculiarities belonging to the spermatosomes are observed in many of the lower vertebrates, as well as in the higher animals and man, notably a tail fiber and an undulating membrane. The head consists of almost pure chromatin and is the nucleus of the transformed cell. In the middle piece the centrosome is represented and the tail fiber, which is characterized by whip-like movements, is probably protoplasmic. In the fresh state the head appears dark, the middle piece quite clear and transparent.

The mature spermatosomes of man are about 50 μ long; the head is elliptic, about 4 μ long and $2\frac{1}{2}$ μ broad, with the anterior end somewhat flattened, so that in lateral view it appears pear-shaped. The middle piece is narrow, short, cylindric, and the tail fiber is long. The *spermato-*

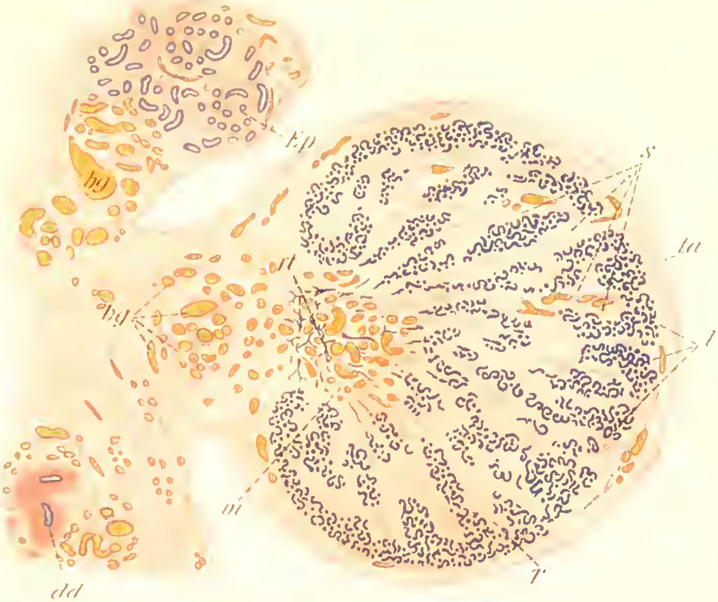


Fig. 1.

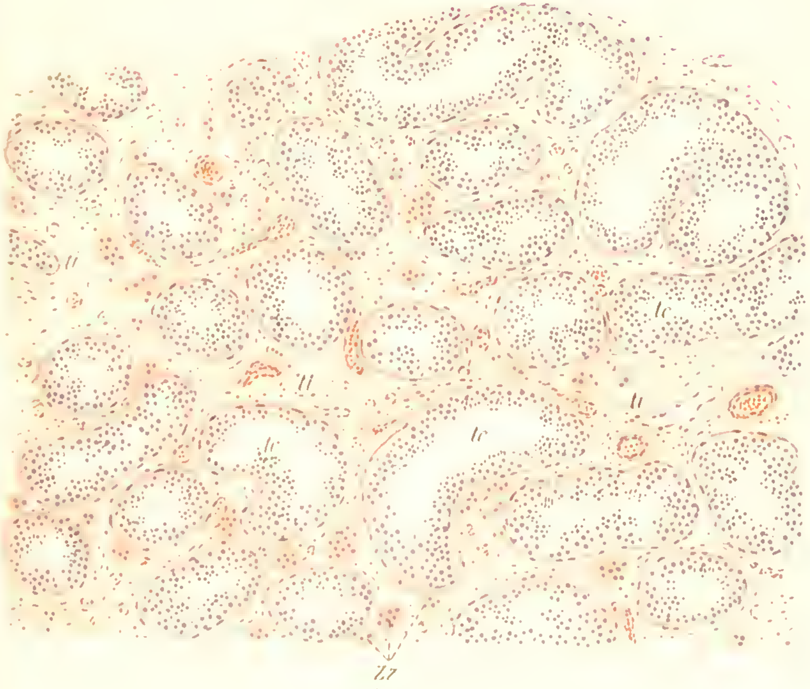


Fig. 2.

somes arise directly from one of the cells of the tubules of the testis, the so-called *spermatids,* or sperm-cells. These arise by mitotic division from the mother sperm-cells, or *spermatocytes.* The spermatocytes arise from the primordial cells, or the *spermatogones.*

Besides the three generations of cells whose end-products are the cellular secretion of the testis, the spermatosomes, another variety of epithelial cell is found in the epithelium of the tubuli contorti of the testis, which takes no part in the process of spermatogenesis, but which serves as a *supporting element* for the mature spermatosomes. These cells are known as *Sertoli's cells.* Each cell has an elongated nucleus, often pointed toward the lumen of the tubule; in comparison with the nuclei of the other epithelial cells of the testis, it is noteworthy on account of the small amount of chromatin. In the resting state the nucleus is surrounded by a small amount of protoplasm. In most mammalia the nuclei of the Sertoli cells lie adjacent to the wall of the tubule. In man, however, the nuclei of the Sertoli cells lie nearer to the lumen of the tubule, so that the pedicle of the spermatoblasts is very short.

The *transformation* of the spermatids into *spermatosomes* takes place in the following manner: The spermatids are quite small round cells with spheric nuclei. The cells assume an oval form, the nuclei being also elongated. The latter become rich in chromatin and at the same time smaller. The nucleus then recedes to the side of the cell away from the lumen of the canal. A group of these metamorphosed spermatids now enter into close relation with a *Sertoli cell,* with the protoplasm of which their protoplasm fuses. By this means a structure develops, which is called a *spermatoblast.* Each spermatoblast consists of the nucleus of the Sertoli cell, generally lying next to the sheath of the tubule, of a protoplasmic pedicle, and of a broad protoplasmic mass adjoining the lumen of the tubule and consisting of the fused cell-bodies of the spermatids.

PLATE 54.—TESTIS.

The figures of this plate represent portions of the convoluted tubules of the human testis, during the process of spermatogenesis.

The material for the preparation was removed by an operation, secured by Professor Benda, of Berlin, and was fixed in potassium bichromate-nitric acid. Iron-hematoxylin-eosin.

FIG. 1.—**Portion of the Wall of the Tubule of the Testis, Shortly After the Evacuation of a Generation of Spermatosomes.** × 420.

The figure still shows some spermatosomes, which lie between the innermost layers of spermatids and several layers of spermatogones; between the latter and partly also between the spermatocytes are seen the nuclei of the Sertoli cells; all cells are in the resting state. Outside is seen the membrane of the tubules, with flattened nuclei.

FIG. 2.—**A Spermatoblast under Higher Magnification.** × 500.

FIG. 3.—**Portion of a Seminal Tubule, in which the Transformation of the Spermatids into Spermatosomes is Going on.** × 420.

The spermatids are elongated, their nuclei are small, rich in chromatin and excentric, but they have no connection with the Sertoli cells.

FIG. 4.—**Portion of a Seminal Tubule in the Stage of Spermatoblasts.** × 420.

The maturing spermatosomes with the Sertoli cells form complexes called spermatoblasts. Otherwise we find only spermatocytes and spermatogones.

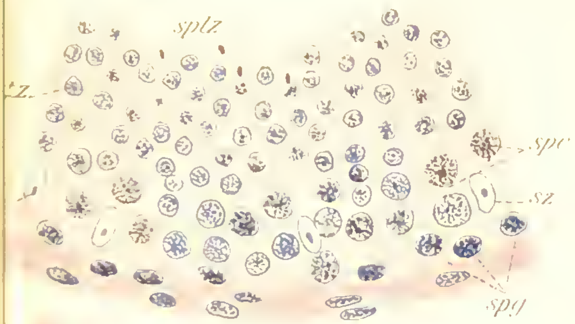
FIG. 5.—**Portion of a Seminal Tubule in the Stage of Division of the Spermatocytes.** × 420.

The spermatoblasts are present. The spermatocytes are seen partly in mitotic division and partly already divided.

Reference letters for Figs. 1, 3, 4, and 5: *h*, Connective-tissue sheath; *mi*, mitoses in spermatocytes; *spbl*, spermatoblasts; *spc*, spermatocytes; *spg*, spermatogones; *spt*, spermatids; *sptz*, spermatozoa; *sZ*, Sertoli's cells.

As the elongated cell-bodies of the spermatids do not entirely fuse with the spermatoblast, this structure presents toward the lumen peculiar processes corresponding to the elongated cell-bodies of the spermatids. In this protoplasm the nuclei of the spermatids undergo the entire transformation into the heads of the spermatosomes, while at the same time the centrosomes of the spermatids form the middle piece of the spermatosomes. The contractile tail filaments develop from the protoplasm of the spermatids and probably also in part from that of the spermato-

Tab. 54.



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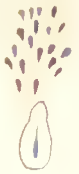

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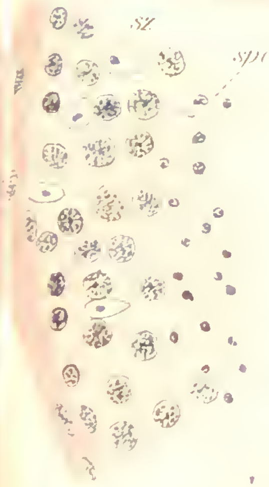

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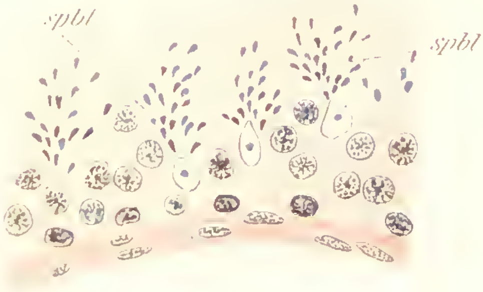

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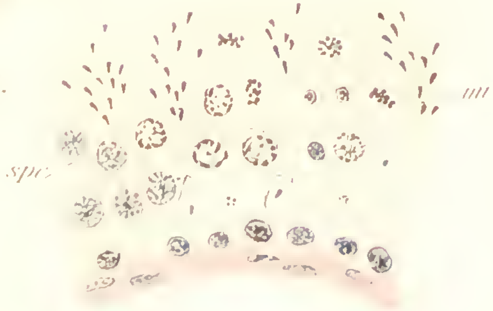


Fig. 5

blasts. The greater portion of the protoplasm of the spermatoblasts is not used in the formation of the spermatosomes, but breaks up in the lumen of the tubule after these have entirely matured and been set free.

With the maturing of the spermatosomes and their extrusion into the lumen of the tubules, their union with the spermatoblasts ceases and the Sertoli cells return to the resting state, later to enter into connection with new generations of spermatids and form spermatoblasts. As the secretion of the testis consists of cells arising from the transformation of the epithelial cells of the convoluted tubules of the testis, the cells thus used must be replaced by the division of the remaining cells. This is done by the mother sperm-cells, which are again regenerated by the spermatogones.

The *spermatogones* lie between the Sertoli cells and the periphery of the tubule; they are quite small round cells with nuclei rich in chromatin. By division of a spermatogone there are formed two daughter cells, one of which retains the position of the spermatogone near the wall of the tubule and remains a spermatogone; the other daughter cell, which is situated toward the interior of the tubule, becomes a mother sperm-cell or spermatocyte, and increases considerably in size.

The *spermatocytes* are large round or polygonal cells, with large nuclei, which show a distinct network of chromatin fibers. They lie in one or two layers between the spermatids and spermatogones. By means of two mitotic divisions, which succeed each other with slight intermission, they produce a generation of much smaller cells, the above-described *spermatids*, which are in several layers. It may therefore be seen that the convoluted tubules of the testis have a different appearance, according to the stage of spermatogenesis. It may be stated that in many vertebrates, and especially in certain of the lower vertebrates, the processes of spermatogenesis can be observed much more distinctly than in man.

PLATE 55.—EPIDIDYMIS.

FIG. 1.—**Portion of a Transverse Section of the Epididymis.** × 80.

The preparation was taken from a man who had been executed.

The figure shows the cross-sections of the ductuli efferentes testis.

Technic: Zenker's solution. Hematoxylin-eosin.

Reference letters: *bdg*, Connective tissue; *m*, muscularis; x, crypts of epithelium.

FIG. 2.—**Portion of Transverse Section of the Epididymis.** × 80.

The preparation was taken from a man who had been executed.

The figure shows the convoluted ductus epididymidis cut several times.

Technic: Zenker's solution. Carmin-hematoxylin-eosin.

Reference letters: *bdg*, Connective tissue; *c*, capillaries; *ep*, epithelium; *L*, lumen; *lc*, leukocytes; *m*, muscularis; *mp*, membrana propria; x, portions of the canal cut tangentially.

The tubuli seminiferi contorti pass directly into the tubuli recti and the *rete testis*. The tubuli recti are very small canals, lined by cubic or pavement cells in a single layer. The tubuli recti unite to form a tubular network, situated in the mediastinum testis and known as the rete testis. The anastomosing tubules or spaces of the rete testis are lined by a non-ciliated flattened or cubic epithelium. From the tubular network arise from twelve to fifteen tubules, the vasa efferentia, which pass to the globus major of the epididymis.

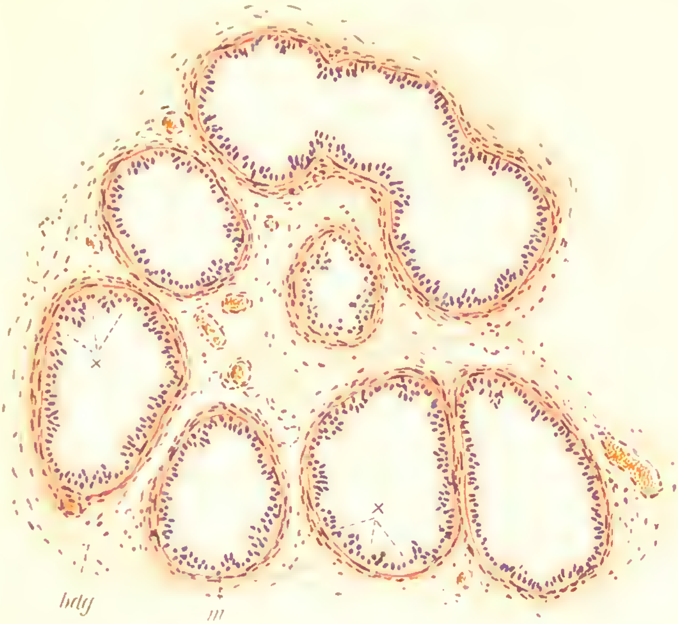
The *blood-vessels* of the testis form dense capillary networks around the tubuli contorti. Numerous lymph-canals are found especially under the tunica albuginea.

The *nerves* of the testis are non-medullated sympathetic fibers, whose manner of ending has not yet been fully determined, although they have been traced to the walls of the tubuli contorti.

THE EFFERENT SEMINAL PASSAGES.

The tubules of the *epididymis*, comprising the *vasa efferentia* and *ductus epididymidis*, the *vas deferens*, the *seminal vesicle*, the *prostate* and *urethra* (see page 174), together

Tab. 55.



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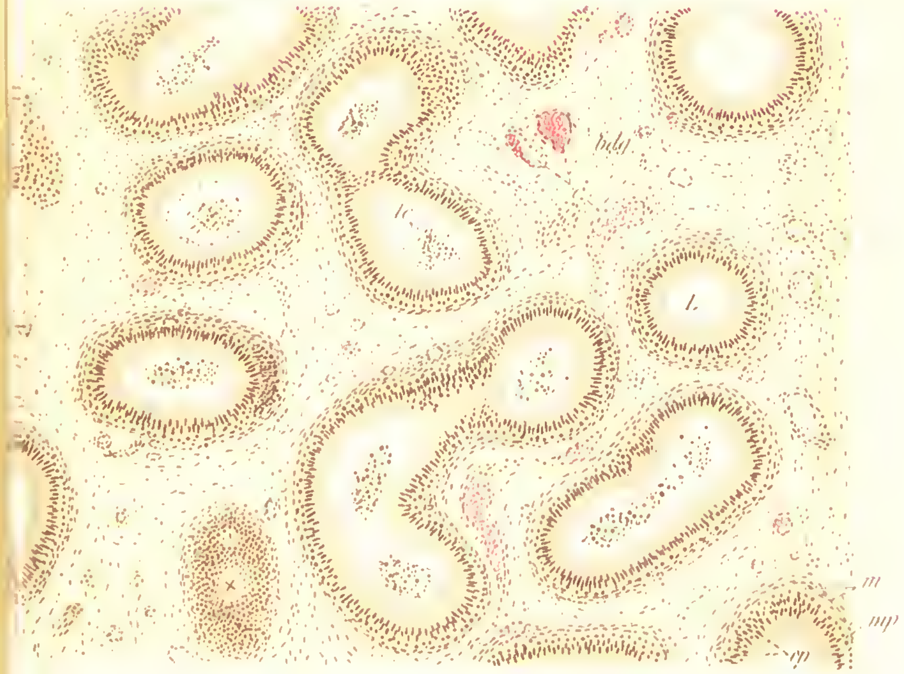

Fig. 2.

with the smaller and larger *glandular structures*, belong to the efferent seminal passages. The vasa efferentia are large canals and are lined with two kinds of epithelial cells; the cells of one variety are of relatively high columnar shape; of the other, low cubic. The cubic cells lie between groups of the columnar cells, so as to form intra-epithelial crypts. These crypts are regarded as intra-epithelial glands. The columnar cells are usually, though not always, ciliated, making the crypts appear still deeper. The epithelium is surrounded by a single layer of smooth muscle-cells and a thin layer of connective tissue. The vasa efferentia unite to form the *ductus epididymidis*, which is much convoluted in the body of the epididymis and is lined by a stratified ciliated epithelium, consisting of two layers of cells (see page 31).

The layer of cells lying next to the lumen consists of very high, narrow, cylindric cells, whose nuclei alternate—that is, are at different levels. They bear long whip-like cilia, each cell having but a small number. The cells of the lower layer are spheric or somewhat flattened cells (see Plate 3, Fig. 3).

Outside of the membrana propria there is found a relatively thin layer of non-striated muscle-cells, which is usually much more distinct in the lower portion of the epididymis, and especially at the transition into the vas deferens, than in the upper portion.

The **vas deferens** is a long canal with relatively narrow lumen, and especially well-developed muscular walls. Its *epithelium* is similar to that of the ductus epididymidis, consisting of a two-layered stratified ciliated epithelium. It is seldom, however, that the ductus deferens is ciliated throughout. Attention may here be drawn to the fact that the epithelium of the seminal ducts, like much of the epithelium of the seminal passages, undergoes manifold variations. The *mucosa*, which can scarcely be separated from the submucosa, contains no glands, but many elastic fibers. The *muscularis* is very well developed and forms

PLATE 56.—SEMINAL PASSAGES, SPERMATIC CORD.

FIG. 1.—**Transverse Section of the Lower Portion of the Vas Deferens of Man.** × 25.

The preparation was taken from a man who had been executed.

The figure gives a general view of the lamination of the wall of the seminal duct in the neighborhood of its opening into the prostate.

Technic: Müller's fluid. Hematoxylin-eosin.

Reference letters: *alm*, External longitudinal layer of muscle; *ep*, epithelium; *g*, blood-vessels; *ilm*, inner longitudinal layer of muscle; *L*, lumen; *rm*, circular layer of muscle; *ta*, tunica adventitia.

FIG. 2.—**Transverse Section of the Spermatic Cord of Man.** × 10.

The preparation was taken from the spermatic cord of a man who had been executed.

The figure shows the spermatic cord without its sheaths, also the ductus deferens, the plexus venosus pampiniformis, arteries and nerves.

Technic: Zenker's solution. Hematoxylin-eosin.

Reference letters: *a*, Arteries; *dd*, transverse section of the seminal duct, with highly developed external longitudinal muscular layer; *F*, adipose tissue; *n*, nerves; *v*, muscular veins; x, valves of a vein.

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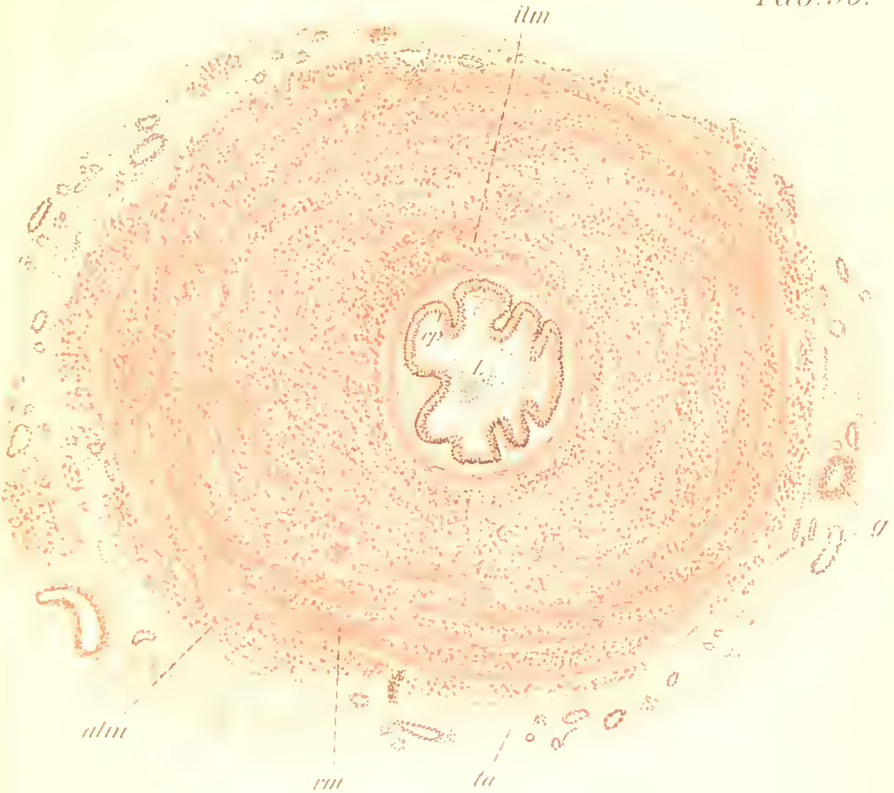
nearly nine-tenths of the entire thickness of the wall. Its lamination varies in the course of the duct. At first, in the neighborhood of the epididymis, there is an inner longitudinal, a middle circular, and an outer longitudinal layer. In the terminal portion, a thin inner circular layer is added and the other layers are often not so distinctly separated. The external connective-tissue sheath of the ductus deferens contains many blood-vessels and also sympathetic nerves. In the region of the **spermatic cord** we find, in addition to the ductus deferens, the veins of the *pampiniform plexus;* these veins have a thick muscle coat and contain valves. In the cord are also found branches of the internal and external spermatic arteries and the fibers of the cremaster muscle.

The *ampulla* of the ductus deferens, the **seminal vesicle,** and the *ejaculatory duct* present essentially the same structure. The non-ciliated columnar epithelium of the seminal vesicles frequently contains pigment granules. Besides the macroscopic folds of the muscular walls of the seminal vesicles, the mucous membrane shows many micro-



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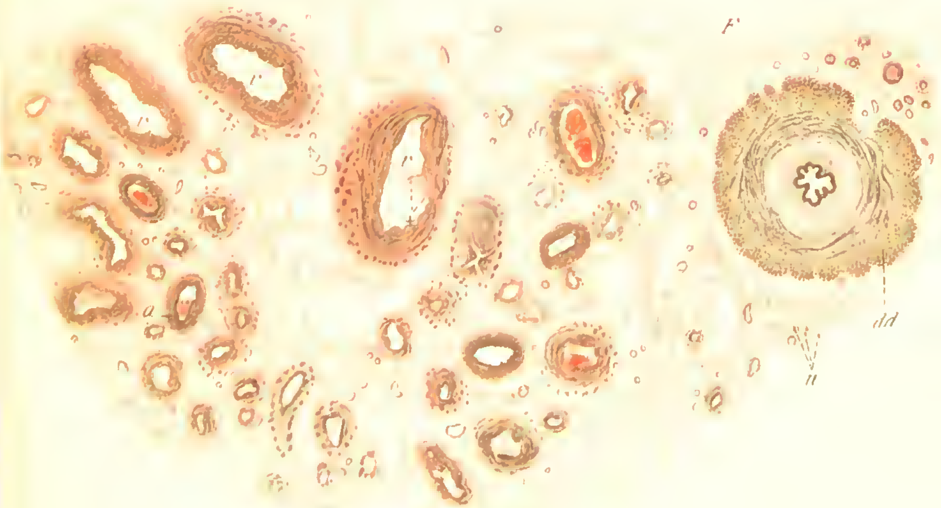

Fig. 2.

scopic folds, which form smaller and larger diverticula of the mucous membrane. In addition to these, there are in the poorly differentiated submucosa larger and more richly branched diverticula and also branched tubular glands. The musculature of the seminal vesicle is irregularly arranged, but it contains mostly circular fibers. In the neighborhood of the human seminal vesicles we often find small sympathetic ganglia of the myospermatic plexus. The secretion of the seminal vesicle is mucous. It usually contains no spermatozoa. In many animals, especially rodents (mouse, rat, guinea-pig), the secretion of the seminal vesicle is ejaculated after the evacuation of the semen. It consists of a mass which soon solidifies and closes the vagina as a vaginal plug for about twenty-four hours. These animals have very highly developed seminal vesicles.

The **prostate** is an organ composed of glandular tissue, a relatively large amount of non-striated muscle, and a relatively small amount of connective tissue; it surrounds the beginning of the urethra. The glandular part of the prostate consists of a number of branched tubular or tubulo-alveolar glands, opening into the urethra by separate excretory ducts; these have a relatively large lumen and are lined by columnar or cubic epithelial cells. These cells resemble the serous cells of the salivary glands more than they do the mucous cells. Especially at advanced age the enlarged lumina of the prostate gland contain stratified concretions of a brownish color, the so-called *prostatic calculi.* Between the separate glands and between the alveoli of the glands, many smooth muscle-fibers are found separated by a small amount of connective tissue.

The **glandula bulbourethralis,** or Cowper's gland, is tubulo-alveolar, as its terminal compartments are partly tubular and partly saccular. Like the smaller glands of the urethra, it contains cells which resemble the mucous cells of the salivary glands. Its excretory duct opens into the membranous portion of the urethra.

The *epithelium* of the **male urethra** varies in the different

PLATE 57.—URETHRA, SEMINAL VESICLE.

FIG. 1.—**Transverse Section of the Pars Membranacea of the Male Urethra.** × 18.

The preparation was taken from a man who had been executed.

The figure gives a general view of the structure of the male urethra under low magnification.

Technic: Müller's fluid-formalin. Hematoxylin-eosin.

Reference letters: *bg*, Blood-vessels of mucous membrane (veins); *ep*, epithelium; *gl*, urethral glands (Littré); they lie partly in the submucosa (at the left) and partly in the muscularis; *lm*, longitudinal muscle; *L*, lumen; *rm*, circular muscle; *tp*, tunica propria or mucous membrane.

FIG. 2.—**Transverse Section of the Upper End of the Human Seminal Vesicle.** × 12.

The preparation was taken from a man who had been executed.

The figure represents a slightly magnified general picture.

Technic: Zenker's solution. Hematoxylin-eosin.

Reference letters: *bg*, Blood-vessels in the adventitial connective tissue; *ep*, epithelium; *gl*, gland-like crypts of the mucous membrane; *L*, lumen; *M*, muscularis; *S*, secretion retracted from the wall by shrinking; *tp*, tunica propria or mucous membrane.

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portions. The beginning—to the opening of the ejaculatory ducts—has still the transitional epithelium of the efferent urinary passages. The remaining portion of the male urethra has generally stratified columnar epithelium, while the terminal portion, the fossa navicularis, is lined by stratified pavement epithelium, similar to the epithelium of the glans penis.

PLATE 58.—PROSTATE.

FIG. 1.—**Portion of a Transverse Section of the Prostate of an Adult.** × 45.

The preparation was taken from a man who had been executed.

The figure shows the prostatic gland tubules of very different size and width, within a tissue which is very rich in smooth muscle-fibers and relatively poor in connective tissue.

Technic: Zenker's solution. Hematoxylin-eosin.

Reference letters: *ts*, Gland tubules; *m*, musculature.

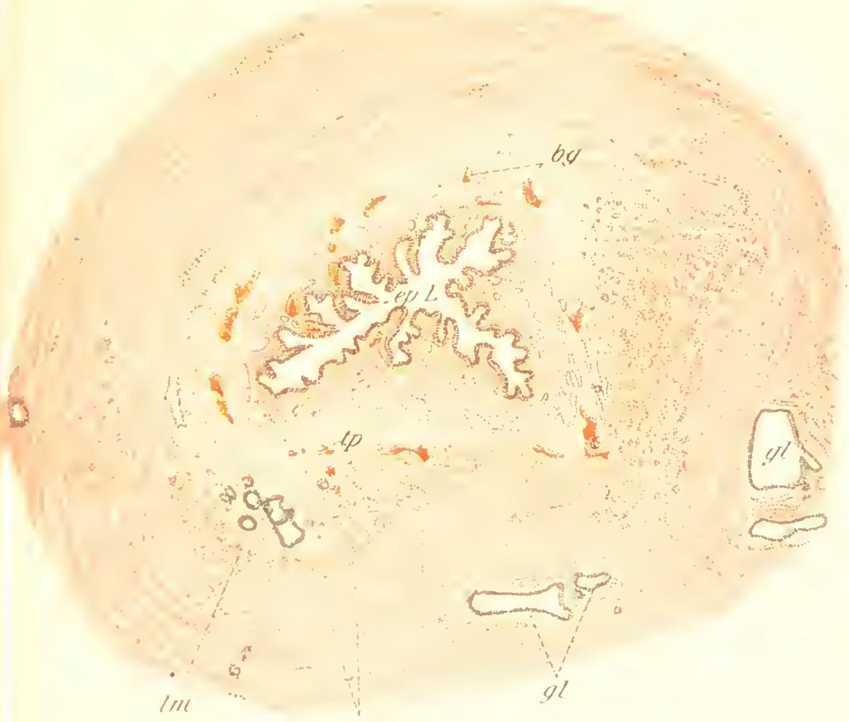
FIG. 2.—**Portion of the Wall of a Distended Urinary Bladder of a Frog.** × 80.

The figure shows the reticular arrangement of the smooth muscle, with connective-tissue cells lying between. The epithelium is absent.

Technic: Filling of the bladder with a solution of potassium chromate. Penciling off the epithelium. Hematoxylin-eosin.

Reference letters: *glm*, Smooth muscle-fibers; *bz*, connective-tissue cells.

Tab. 57.



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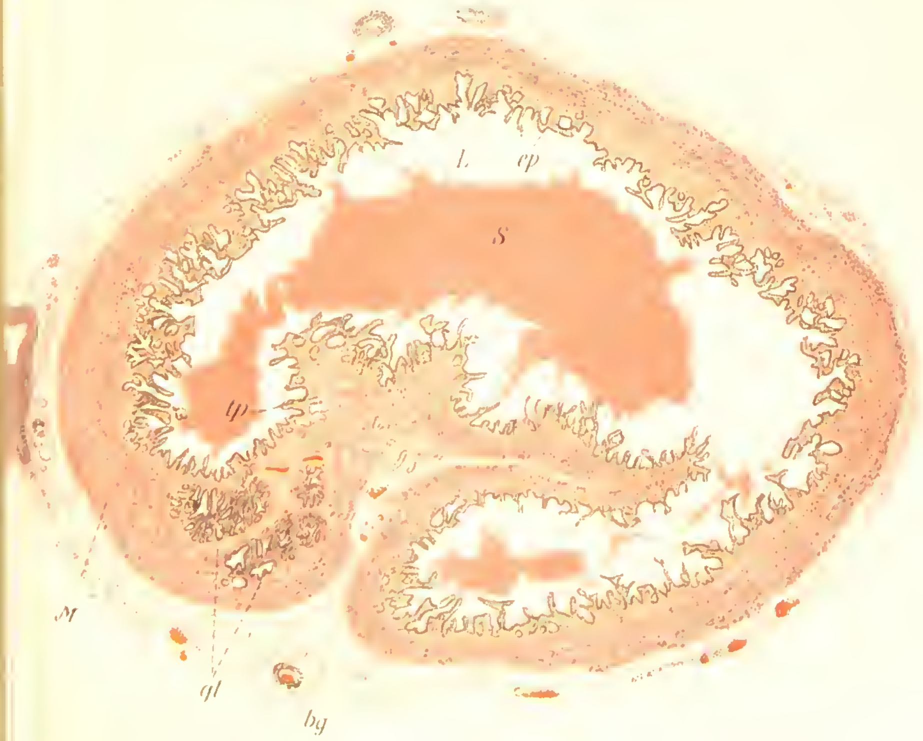
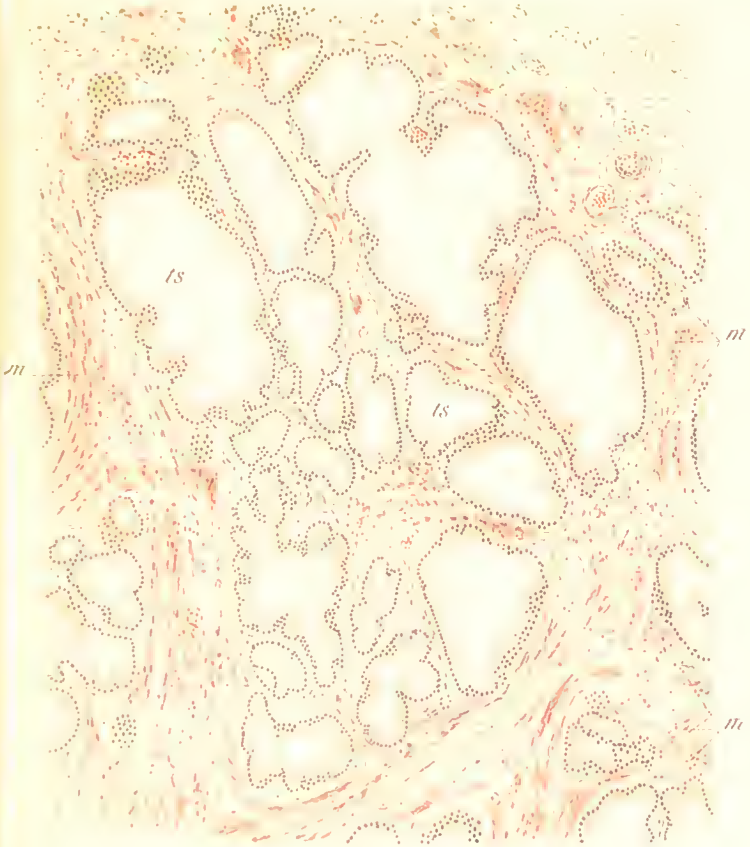


Tab. 58.



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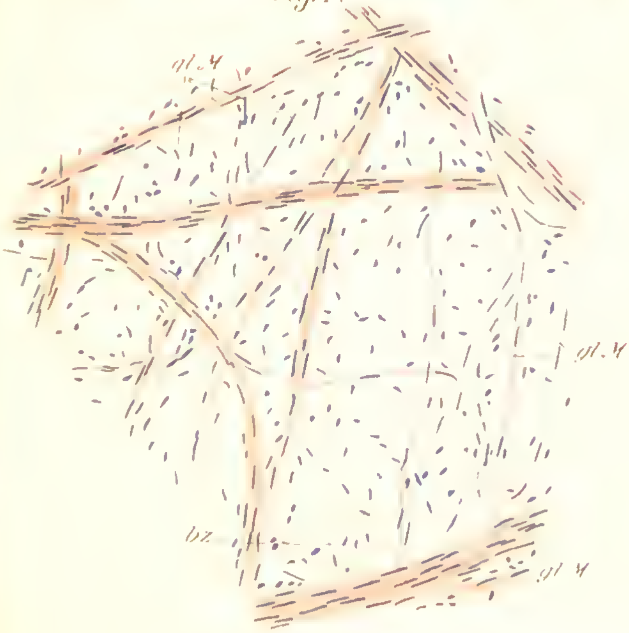

Fig. 2.

The *mucous membrane* of the male urethra in the pars membranacea and cavernosa is rich in elastic fibers and, like the submucosa and the adjacent parts of the muscularis, contains many wide veins, which form plexuses. Mucous membrane and submucosa are quite intimately connected, since there is no muscularis mucosæ. The submucosa contains branched tubulo-alveolar glands, small *mucous glands*, known as the glands of Littré.

The *musculature* of the urethra consists of two not very distinctly separated layers of non-striated muscle, a thinner inner longitudinal layer and a thicker external circular layer. In the prostatic and membranous portions, striated muscle-fibers from the musculus transversus perinei profundus are added.

The **penis** consists essentially of the three cavernous bodies: the two corpora cavernosa and the corpus spongiosum containing the urethra. The corpora cavernosa have a strong connective-tissue sheath, the *tunica albuginea*, and within this a meshwork of connective-tissue septa, in which are found non-striated muscle-fibers. The meshes are *blood sinuses*, into which, without changing into capillaries, the arteries of the penis open. The tunica albuginea of the *corpus spongiosum* is not so well developed as that of the corpora cavernosa. In the corpus spongiosum, arteries open into the blood spaces of the meshes by means of capillaries. Otherwise the structure is the same as that of the corpora cavernosa of the penis. The skin of the glans penis, as well as the mucous membrane of the urethra, contains free nerve-endings and also endings in the genital corpuscles.

VIII. THE FEMALE REPRODUCTIVE ORGANS.

The **ovary** is a gland having no direct excretory duct (see page 39). In comparison with the ovaries of many animals, the human ovary is very rich in connective tissue,

PLATE 59.—OVARY.

FIG. 1.—**Transverse Section through the Cortex of a Human Ovary.** × 50.

The preparation was taken from a fifteen-year-old girl (Professor K. W. Zimmermann, of Bern).

The figure shows in the outer zone of the cortex numerous primordial follicles and deeper in the tissues a larger Graafian follicle.

Reference letters: *A*, Tunica albuginea; *ep*, follicular epithelium; *fp*, primordial follicles; *ov*, ovulum in the discus proligerus; *the*, theca externa folliculi; *thi*, theca interna folliculi with blood-vessels.

FIG. 2.—**The Ovum, a Portion of the Discus Proligerus of Fig. 1 under Higher Magnification.** × 300.

The figure shows the ovum with its nucleus, the germinal vesicle, surrounded by the zona pellucida, within the epithelial cells of the discus proligerus, part of which show mitoses.

Reference letters: *Oo*, Zona pellucida; *Kf*, germinal spot.

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so that in comparison with the well-developed stroma of the albuginea and of the cortex, the parenchyma formed by the ovarian follicles is not prominent. The *cortical substance* of the ovary is surrounded by a firm fibrous connective-tissue *albuginea* consisting of a felt-work of connective-tissue bundles. In the cortex is found the parenchyma of the ovary. The medullary substance lies in the neighborhood of the hilus ovarii and contains the blood-vessels entering the organ, especially many veins. The *surface* of the ovary is covered by *peritoneum* in such a way that the connective tissue of the latter fuses with the stroma of the ovary, while the peritoneal epithelium, in the form of low columnar or cubic cells, covers the surface of the organ. It is seen most distinctly in this form in the ovary of the new-born and is known as *germinal epithelium*, since from it the entire parenchyma of the ovary is developed. The *cortical substance* of the ovary contains numerous bundles of connective tissue which connect with the albuginea. Between them lie the ovarian follicles, so-called Graafian follicles, in various stages of development, the youngest being nearest to the tunica albuginea. The number of fully developed follicles is always small.

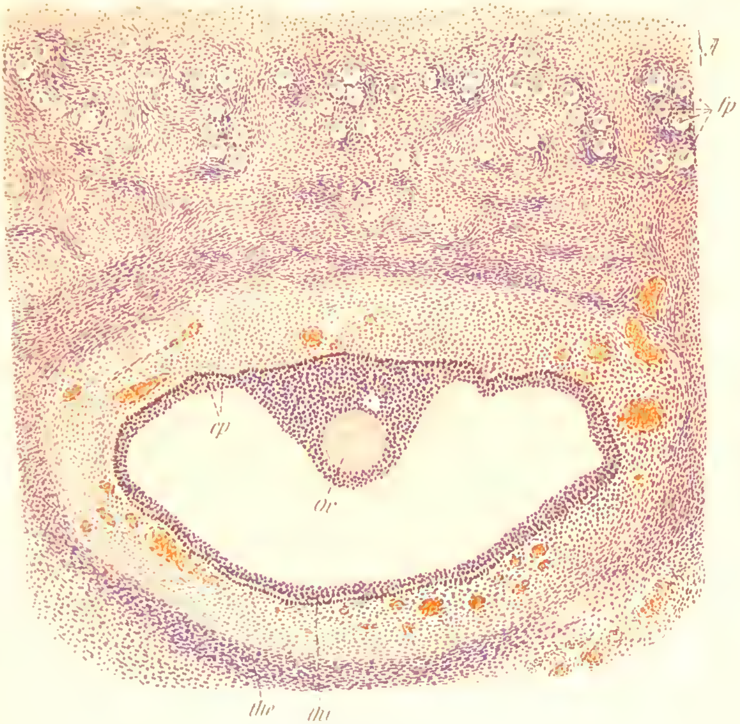


Fig. 1.

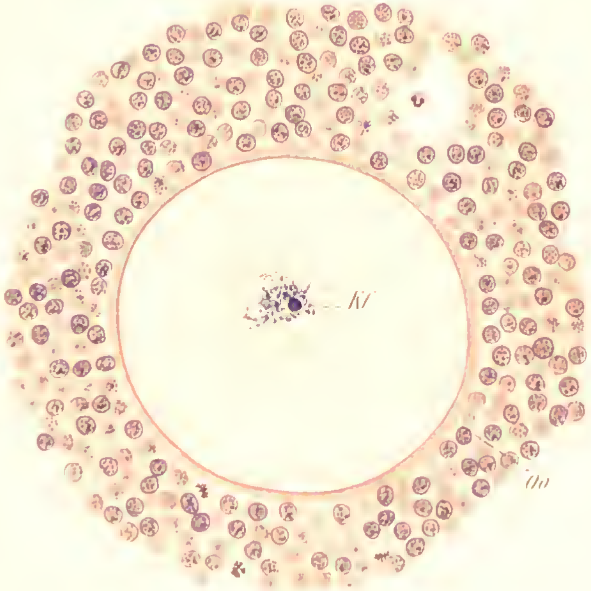


Fig. 2.

The process of development of ova and ovarian follicles may be recognized in the new-born and for some time after birth. Some cells of the germinal epithelium of the surface of the ovary increase in size by growth of the cell-body, until they attain a relatively large size and spheric form. Such cells are known as primordial ova or primary eggs. Generally, several primordial ova are inclosed by germinal epithelial cells, forming a plug-like growth of the germinal epithelium, which penetrates the cortical substance and constitutes the *egg-balls* or egg-nests, so-called Pflüger's tubes. Pflüger's tubes, or the egg-nests, are not hollow, but solid structures. Within the egg-nests each primordial egg is surrounded by a single layer of flat to cubic cells, the *follicular cells*, and a *primordial* or *primary follicle* is thus formed. The primordial follicles lie in large numbers close under the albuginea in the outer layer of the cortex. The further development goes on from these to the mature Graafian follicles, the older and larger follicles being pushed deeper into the cortical substance, and thus nearer to the limits of the medullary substance.

The growth of the ovarian follicle proceeds in the following manner: There is first a *proliferation of the epithelial cells* of the follicle, the egg-cell being in this way surrounded by several layers of cells. At the same time a connective-tissue sheath from the ovarian stroma is formed around the entire follicle, known as the *theca folliculi*. As the ovum develops, it becomes surrounded by a structureless or radially striated sheath, the zona pellucida. The zona pellucida very probably arises from the ovum itself and is to be regarded as a cell membrane. In many animals—whether in man is doubtful—the outer portion of it appears to be formed by the adjacent portions of the follicular epithelium.

In the further growth of the ovarian follicle and with further proliferation of the follicular epithelium there is an excretion of *fluid* on the part of the follicular epithelium, the *liquor folliculi*. This forms between the cells in

Fig. 56.—Graafian follicle of the ovary of the mouse in different stages of development. × 200. The figure shows the proliferation of the epithelium and the formation of the liquor folliculi. *c*, Yolk nucleus (centrosome); *E*, ovum; *ef*, follicular epithelium; *k*, nucleus of ovum; *lf*, liquor folliculi; *thf*, theca folliculi.

Fig. 57.—Portion of a cross-section through a fully developed corpus luteum of a mouse. × 375. The figure shows the relation of the hypertrophied epithelial cells to the blood capillaries and connective-tissue cells. *c*, Capillaries; *ep*, epithelial cells of the corpus luteum; *kbdg*, connective-tissue nuclei.

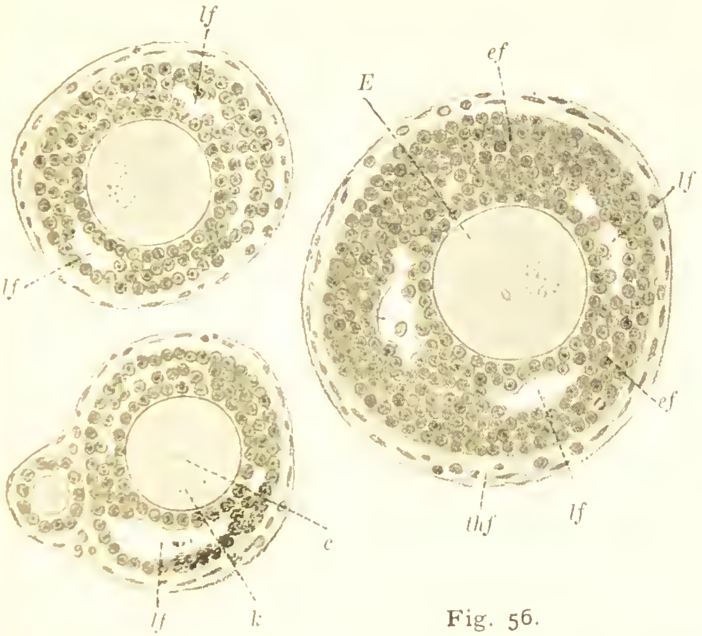
Fig. 58.—Small portion of a cross-section through an older corpus luteum of a mouse. × 600. The epithelial cells contain fine fat droplets, blackened by osmic acid.

one place or at the same time in several places of the follicular epithelium, so that now the follicle assumes the form of a vesicle. In this process the ovum is generally crowded toward one wall by the collection of fluid.

The follicular epithelium generally consists of polygonal cells; only the outer cells bordering on the theca folliculi and those next to the ovum, especially the cells lying next to the zona pellucida, are columnar. The latter constitute the *corona radiata;* the mass of epithelial cells surrounding the ovum are called the *discus proligerus.* On the rupture of the follicle these are evacuated with the ovum. The *theca folliculi* of larger follicles has an outer fibrous and an inner cellular layer, containing fat granules. The ovary of many animals contains a large-celled interstitial tissue, the cells of which resemble those of the inner layer of the theca folliculi and may be mistaken for them.

While the ripening follicles push toward the inner portion of the ovary as their development proceeds, the follicles which have become markedly distended by the collection of fluid again pass toward the surface, a part of their wall touching the tunica albuginea and the surface of the ovary, and thus occupy the entire thickness of the cortical substance. When the attenuated follicular wall ruptures, there is a laceration of the surface of the ovary, which later heals by the formation of scar tissue.

After the rupture of the follicle its walls collapse. The



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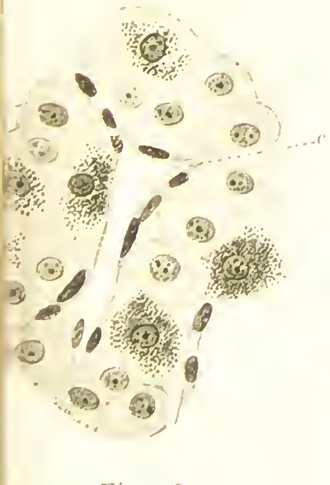

Fig. 58.

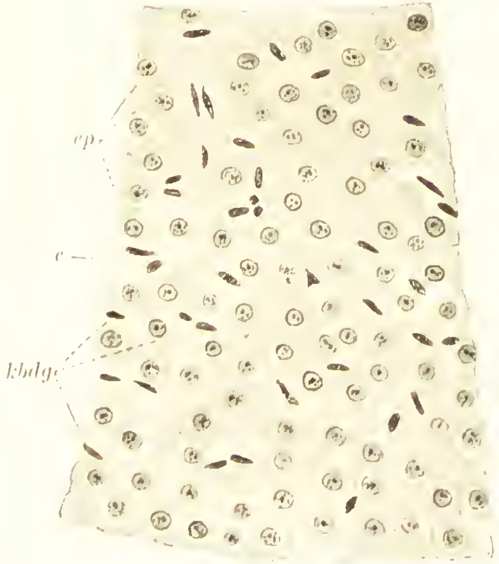

Fig. 57.

follicular epithelium which remains within the follicle hypertrophies, the cells attaining many times their original size. At the same time processes of connective tissue from the theca folliculi containing blood-vessels penetrate between the epithelial cells. The structure which thus develops is known as the *corpus luteum*, because its cells contain a yellowish pigment known as lutein and are therefore designated as lutein cells. Later the structure degenerates, the epithelial cells (lutein cells) undergo fatty degeneration, and the connective-tissue trabeculæ become atrophied, and thus the corpus albicans is formed. On the rupture of the follicle hemorrhages often take place on account of the laceration of the blood-vessels. The remains of such hemorrhages are found in the form of hematoidin crystals. The process of rupture of the follicle and formation of the earlier stages of the corpus luteum has never been observed in the human ovary.

The fully developed follicular *ovum* is a large, almost perfectly spheric cell, which in the human ovary has a diameter of about 250 μ. Its diameter, however, cannot be ascertained with any degree of certainty, since mature human ova—that is, after extrusion from a follicle—have never been observed.

In mammalia its protoplasm contains, in varying, but usually in small amount, fat-like constituents, known as *deutoplasm;* this is found especially in the central portion of the ovum.

The *nucleus* of the maturing ovum is spheric and generally contains a large nucleolus. The nucleus of the ovum has long borne the name of the *germinal vesicle*, and the nucleolus that of the *germinal spot*. The maturing ova of mammalia, and also the human ova, contain, outside of the nucleus, another small structure, the so-called *yolk-nucleus*. It represents essentially the rudimentary centrosome, which usually degenerates in the ovum before the complete maturity of the cell is reached. In the maturation of the ovum a short time before it is expelled from the

PLATE 60.—OVARY, OVIDUCT.

FIG. 1.—**Transverse Section of the Uterine End of the Human Oviduct.** × 30.

The preparation was taken from a twenty-one-year-old woman.

The figure gives a general view of the structure of the oviduct in close proximity to the uterus.

Technic: Müller's fluid. Hematoxylin-eosin.

Reference letters: *A*, Artery; *L*, lumen; *m*, circular layer of muscle; *tp*, tunica propria; *lm*, longitudinal bundles of muscle; *V*, veins.

FIG. 2.—**Portion of a Transverse Section of the Ovary of a New-born Child.** × 280.

The preparation was taken from a still-born child.

The figure shows very distinctly primordial ova in the germinal epithelium, Pflüger's tubes, and groups and masses of primordial follicles.

Technic: Müller's fluid. Hematoxylin-eosin.

Reference letters: *c*, Capillaries; *ke*, germinal epithelium; *str*, stroma; *fp*, primary follicles; *op*, primordial ova.

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ovary, the nucleus withdraws to the surface of the cell and there passes through all the phenomena of mitosis (see page 22). A spindle figure is formed and finally the cell divides in such a way that the egg-protoplasm is divided very unequally into a large egg-cell and a small cell, the so-called first *polar body*.

Many of the primordial follicles formed in the ovary degenerate; and this takes place either in the earlier or later stages of maturation or the ripe follicles fail to rupture and degenerate. The former process is called *atrophy* and the latter *atresia* of the follicles. In both cases, with certain variations, the epithelium degenerates, and finally the egg-cell also. The latter often shows peculiar degeneration phenomena, which may be confused with an apparent division. The zona pellucida is retained the longest.

The *arteries* of the ovary enter from the hilus of the organ and form dense capillary plexuses in the theca of the follicle, especially around the egg-nests. The *veins* form a plexus-like enlargement in the medullary substance. The lymph-vessels have a similar arrangement.

The *nerves* of the ovary arise from the sympathetic, but their manner of ending has not been fully determined.

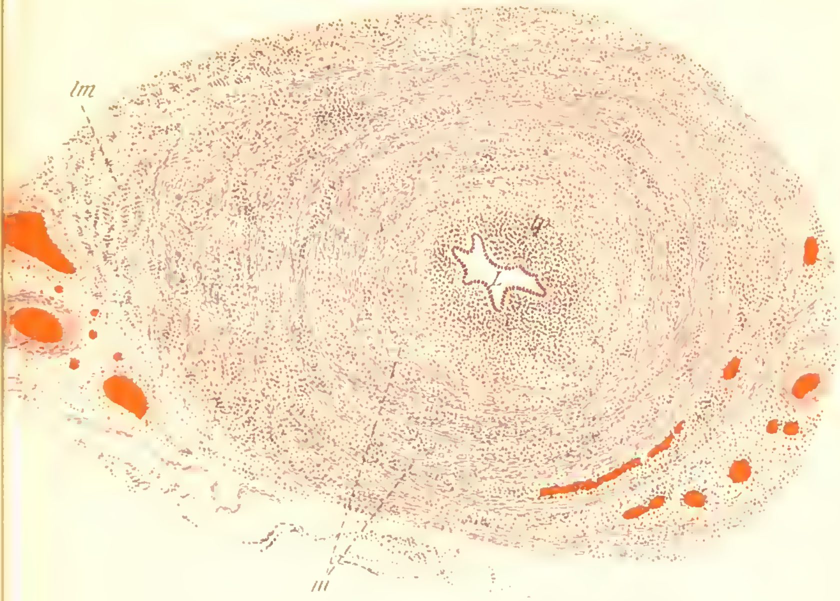

Fig. 1.

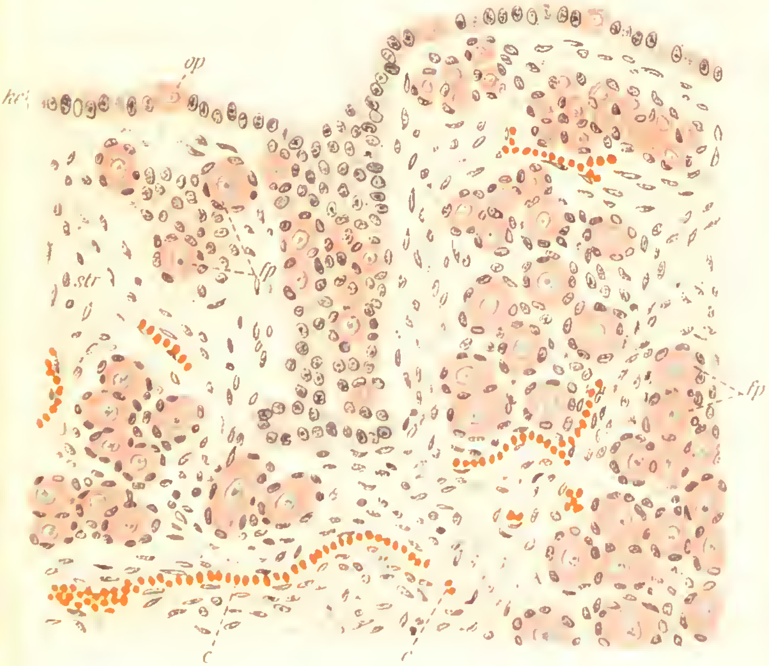

Fig. 2.

THE OVIDUCT, UTERUS, AND VAGINA.

The **oviduct** has a mucous membrane which is slightly folded in the uterine portion, while in the ampullar portion the folds are very high and branched. These are covered by a simple columnar *ciliated epithelium.* The mucous membrane is rich in lymph-cells, and, on account of the want of a muscularis mucosæ, it is poorly differentiated from the submucosa. There are no glands in the oviduct, but in the ampulla there are deep, branched crypts. The *musculature* of the oviduct consists of a thick inner circular layer of non-striated muscle and a thinner external longitudinal layer. To these are added a serosa and a subserosa.

The wall of the **uterus** has similar layers. We distinguish the *mucous membrane*, or endometrium, which, unlike that of the oviduct, contains tubular glands (a submucosa is wanting), the *muscularis*, and the *serosa*, which is attached directly to the muscle without any subserosa. The *epithelium* of the uterus is a simple ciliated columnar epithelium. In the body of the uterus it is low columnar, as in the oviduct, but in the cervix uteri the cells are considerably higher. The mucous membrane of the entire uterus is rich in lymph-cells and resembles a diffuse adenoid tissue (compare page 53). Its entire thickness is filled with simple tubular *glands*, which are either almost unbranched tubules, much convoluted at their blind ends, or they divide at acute angles and may anastomose with each other. These are the *uterine glands*. They are lined with the same kind of epithelium as lines the surface of the uterus. The *musculature* of the uterus is bounded immediately by the mucous membrane and is firmly united with it. It consists practically of circular muscle. However, the arrangement of its elements is by no means regular, as very numerous oblique bundles are found beside and between the circular bundles. Moreover, the large blood-vessels lying in this main muscle layer of the uterus dis-

PLATE 61.—UTERUS.

FIG. 1.—**Transverse Section of the Body of the Human Uterus.** × 2.

The figure gives a general view of the layers of the uterine wall.

Technic: Müller's fluid. Hematoxylin-eosin.

Reference letters: *g*, Blood-vessels of the broad ligament and of the uterine wall; *l*, lumen of the uterus; *ll*, broad ligament; *lm*, longitudinal layer of muscle; *m*, circular layer of muscle; *s*, serosa; *tp*, tunica propria, mucous membrane with the glands.

FIG. 2.—**Transverse Section of the Mucous Membrane of the Uterus.** × 150.

The preparation was taken from a twenty-year-old nullipara. Fixed eighteen hours after death.

The figure shows the lymphoid tissue in the mucous membrane, with the large, convoluted, branched, and anastomosing glands. The muscle layers follow directly upon the mucous membrane.

Reference letters: *ep*, Epithelium; *gl*, uterine glands; *M*, musculature; ×, uterine glands cut tangentially.

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turb the arrangement to a certain extent. The external longitudinal muscle layer, which is well developed in most mammalia and even in the ape, is in the human uterus reduced to a thin layer running in the anterior and posterior surfaces of the organ. The cervical canal is lined by an epithelium which resembles that found in the body of the uterus, although the cells are more slender and much higher. This ciliated epithelium usually extends to the external os, although the stratified vaginal epithelium may penetrate the canal for a distance. In addition to the uterine glands, which are generally present in small numbers in this region, there are also found the cervical glands, which are mucus-secreting glands. These glands often contain mucus plugs, forming the so-called ovula Nabothi. Here there are many individual differences. The longitudinal layer of muscle is more strongly developed than in the body of the uterus.

The *blood-vessels* of the uterus enter the uterus from both sides with the peritoneum (ligamentum latum). The vessels in the uterine wall send branches toward the main

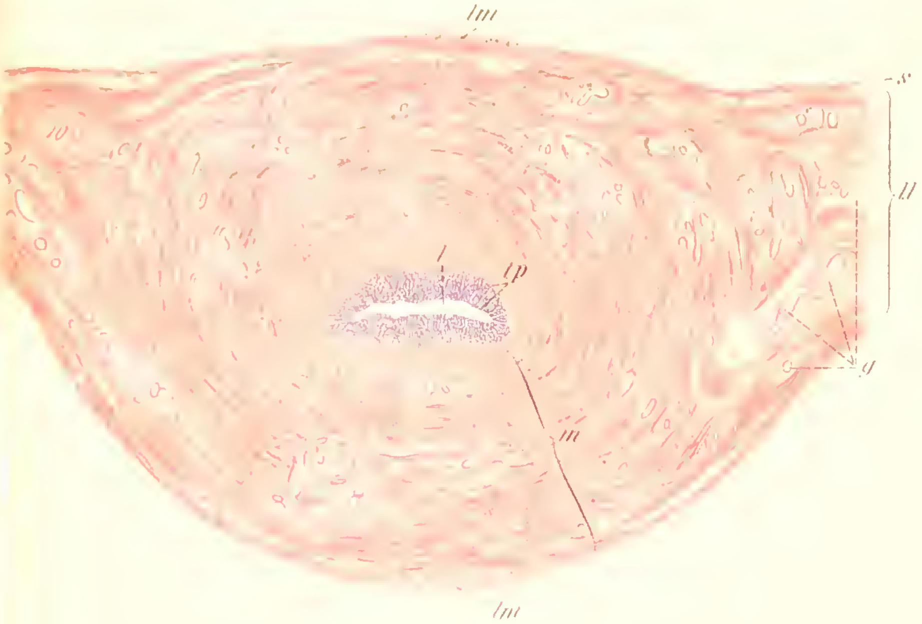

Fig.1.

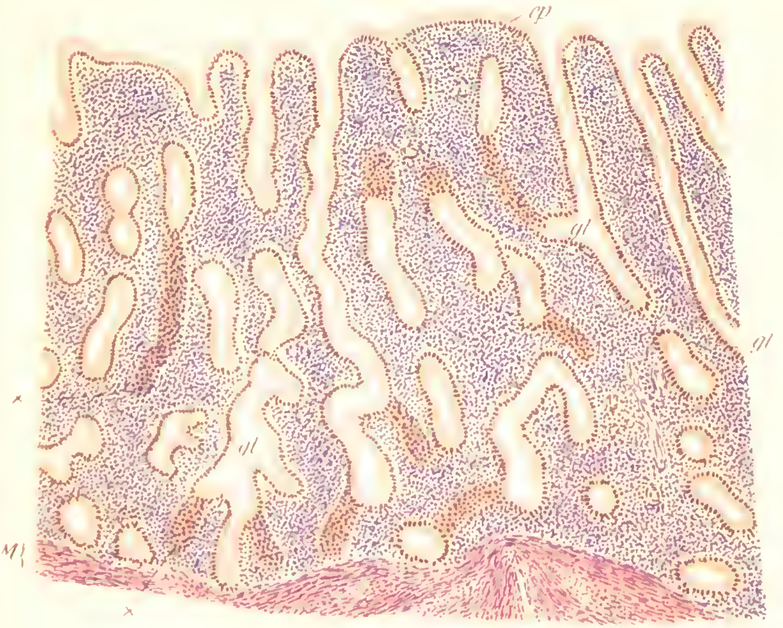

Fig.2.

musculature.[1] From these the distribution proceeds to the vessels supplying the musculature as well as those supplying the mucous membrane. There are many lymph-vessels in the uterus, in the mucous membrane, as well as in the musculature. As in the intestine, the larger vessels are found in the serosa.

The *nerves* of the uterus are for the most part the neuraxes of sympathetic neurones supplying the muscle. It seems very probable that there are cerebro-spinal nerves, the branches of which go to the mucous membrane and end between the epithelial cells.

The **vagina** is lined by stratified pavement epithelium. The mucous membrane presents papillæ, contains no glands, but sometimes has lymph-nodes. A submucosa is present, but is not distinctly differentiated. The musculature consists of smooth muscle-fibers, which form an inner circular and an outer longitudinal layer.

The external female genital organs are in structure partly like the vaginal mucous membrane and partly like the skin. The region of the clitoris and the labia minora contain many sebaceous glands. In the region of the urethral opening mucous glands are found (glandulæ vestibulares minores). The glandula vestibularis major, or gland of Bartholin, is quite similar in structure to the glandula bulbo-urethralis of the male (see page 183).

THE SUPRARENALS.

Although the medullary substance of the adrenal appears to be intimately related to the sympathetic nervous system, the entire organ, according to more recent investigations, is probably to be considered histogenetically in the urogenital apparatus.

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[1] The relation of the blood-vessels to the uterine musculature has given rise to an entirely unwarranted classification of the uterine musculature into a stratum vasculare, supravasculare, and infravasculare or submucosum.

PLATE 62.—SUPRARENALS.

FIG. 1.—**Portion of a Transverse Section of the Human Suprarenal.** × 15.

The preparation was taken from a man who had been executed.

The figure gives a general picture of the larger portion of the adrenal.

Technic: Müller's fluid. Hematoxylin-eosin.

Reference letters for Figs. 1 and 2: *c*, Capillaries of medullary substance; *cf*, capsula fibrosa; *gz*, ganglion-cells; *n*, non-medullated nerve-fibers; *sc*, cortical substance; *sm*, medullary substance; *v*, veins of medullary substance; *zf*, zona fasciculata of the cortical substance; *zg*, zona glomerulosa of the cortical substance; *zr*, zona reticularis of the cortical substance.

FIG. 2.—**Transverse Section through the Cortex and Medulla of a Suprarenal of Man.** × 80.

The preparation was taken from a man who had been executed.

The figure shows the subdivisions of the cortical substance, the cords of cells, the nerves and blood-vessels of the medullary substance.

Technic: Zenker's solution. Hematoxylin-eosin.

The parenchyma of the *adrenal* consists of two distinctly separated portions, the cortical and the medullary substance. In general the cortical substance forms the main mass of the organ, the medullary substance being well developed only in the central portions. The organ is surrounded by a connective-tissue capsule, which sends processes into the interior.

The *cortical substance* consists of radially arranged columns of cells. From the capsule toward the medullary substance we distinguish three zones: First, the *zona glomerulosa;* in this the columns of cells appear as if coiled up. Second, the *zona fasciculata;* this represents the greater portion of the cortical substance and shows most distinctly the radial arrangement of the columns of cells. Third, the *zona reticularis,* in which the columns of cells become again irregular and anastomose in reticular fashion. All the cells of the cortical substance are very similar, of cubic or nearly spheric shape, and often contain fat granules; those of the deeper layers also usually contain pigment granules.

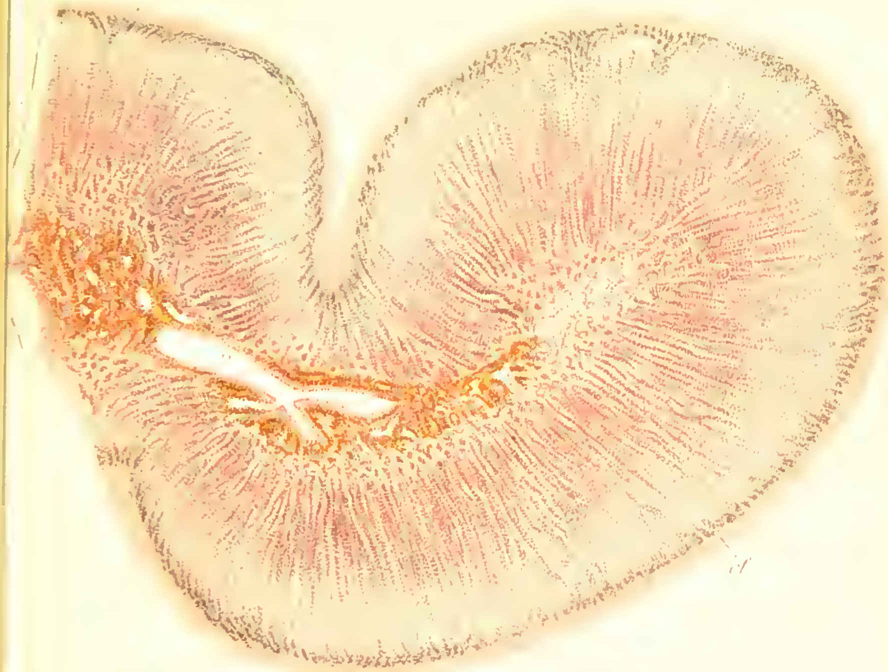

Fig. 1.

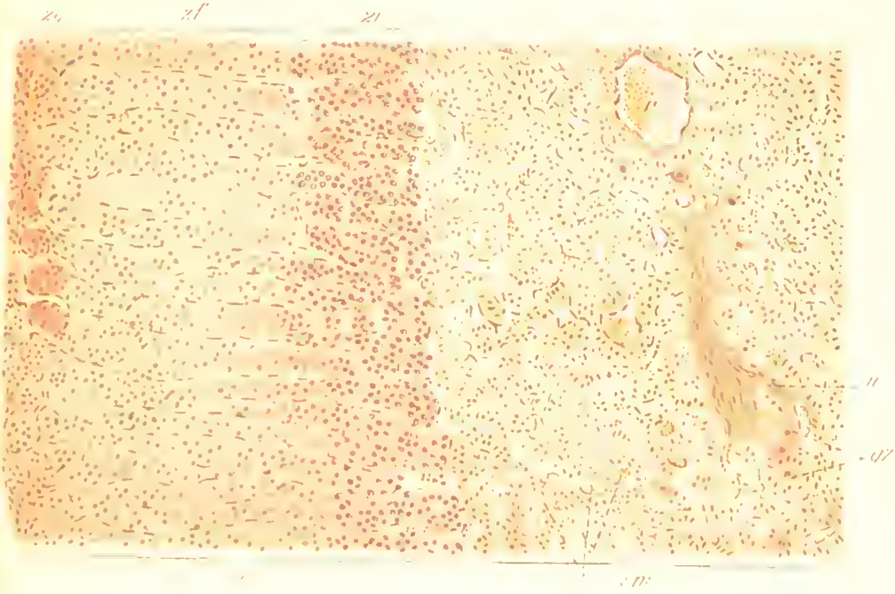

Fig. 2.

The *medullary substance* of the adrenals is not subdivided into zones, but presents throughout the same structure. It consists of peculiar cells, which stain darkly with chrome salts (also called chromaffin cells) and form anastomosing chains. The cells are irregular polyhedral to high columnar in form. The chains often border relatively large vascular lumina or lymph clefts in such a way that each generally oval cell of the medullary substance in transverse section borders the vascular lumen with its two narrow surfaces and the adjoining cells of the chain with its two broader surfaces.

The connective-tissue framework of the adrenal consists of a reticular connective tissue, the fibers of which run parallel to the trabeculæ of cells in the cortex. The adrenal is at the same time very rich in blood-vessels and nerves and probably has intimate relations to both systems.

The *blood-vessels* form numerous capillaries in the cortex as well as in the medulla of the adrenal. Those of the cortex run in general parallel to the columns of cells and between these, at least in the zona fasciculata and reticularis, and in the outer cortical zone form small veins. Besides capillaries, the medullary substance also contains small arteries and especially many plexus-like veins, the walls of which are rich in elastic fibers and often contain thick adventitial bundles of smooth muscle-fibers. The vessels of the medullary substance, especially its capillaries, lie in the spaces between the trabecular network of medullary cells. The *lymph-vessels* of the adrenal are likewise very abundant, especially in the medullary substance.

Numerous non-medullated nerve-trunks of the *sympathetic* enter the adrenal. In their course within the adrenal they often show *ganglion-cells* in smaller or larger groups and occasionally also circumscribed small *ganglia*. The cortical substance is poorer in fibers and ganglion-cells are not found here. The mode of ending of the nerves has not been fully determined.

PLATE 63.—NASAL MUCOUS MEMBRANE.

FIG. 1.—**Portion of a Transverse Section of the Olfactory Region of Man.** × 150.

The preparation was taken from a man who had been executed.

The section shows in cross-section a portion of the olfactory mucous membrane from the superior turbinated bone.

Technic: Zenker's solution. Hematoxylin-eosin.

Reference letters: *ep*, Epithelium; *1*, rod (hair) zone; *2*, zone of long nuclei; *3*, zone of round nuclei; *gl*, olfactory glands; *n*, olfactory nerve; *tp*, tunica propria with blood-vessels.

FIG. 2.—**Portion of a Transverse Section of the Lower Half of the Nasal Wall, Respiratory Region.** × 25.

The preparation was taken from a man who had been executed.

The figure shows the structure of the thick mucous membrane rich in blood-vessels and glands and the adjacent portion of the bone.

Technic as in Fig. 1.

Reference letters: *de*, Excretory duct of the gland; *ep*, epithelium; *gl*, glands; *K*, bone; *tp*, tunica propria.

Occasionally accessory adrenals occur, most frequently in the broad ligament of the uterus and in the neighborhood of the epididymis. In this connection we should mention two small structures of the human body, which are also rich in blood-vessels and nerves—the *carotid gland* (*glomus caroticum*) and the *coccygeal gland* (*glomus coccygeum*). They consist practically of capillary convolutions interspersed with connective-tissue cells rich in protoplasm. According to recent investigations, both types of glands are said to take their origin from the vascular system.

IX. THE RESPIRATORY ORGANS.

THE NASAL CAVITY.

The mucous membrane of the nasal cavity is divided into three portions, the vestibular, respiratory, and olfactory regions. The *vestibular region* presents the structure of the skin, with all its characteristics.

The *respiratory region*, the main portion of the nasal mucous membrane, consists of a typical stratified ciliated

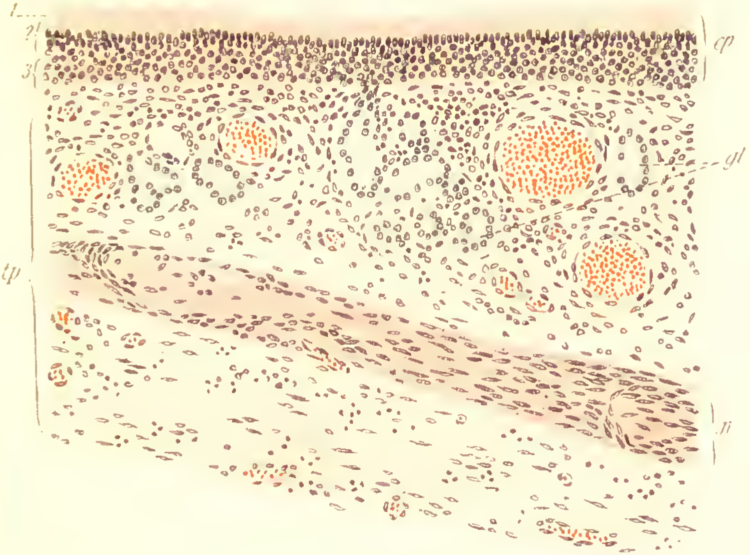

Fig. 1.

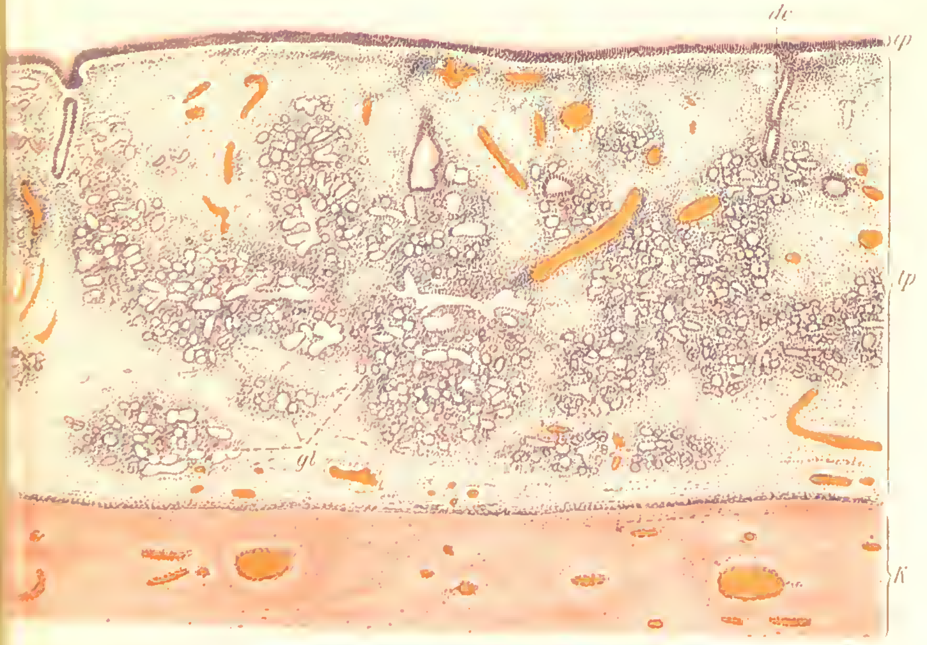

Fig. 2.

columnar epithelium, which often contains goblet-cells, and of a thick mucosa. The latter is connected to the periosteum of the bone and the perichondrium of the cartilage without the intervention of any submucosa. The mucous membrane contains numerous simple branched *tubular glands* of mixed character, containing both serous and mucous cells (see page 37). It is rich in blood-vessels, especially veins. The *accessory cavities* of the nose present a relatively thin mucous membrane, with few glands and a ciliated epithelium in a single layer.

The mucous membrane of the *olfactory region* has a characteristic epithelium, which is thicker than that of the respiratory region. Its upper layer especially consists of very high columnar cells, showing no nuclei in the upper half. The deeper layers are formed by spheric cells. Between the high columnar epithelial cells are found the *olfactory cells* (see page 238). The surface of the columnar cells shows a border resembling a striated cuticular formation (cilia?). The tunica propria of the olfactory region is not so thick as in the respiratory region and contains a special kind of glands, simple tubular serous glands, which are but little branched and are known as *olfactory* or *Bowman's glands.*

The blood-vessels, especially the veins, are somewhat less abundant than in the respiratory region. Numerous bundles of non-medullated olfactory nerves are found in the mucosa under the olfactory epithelium.

LARYNX, TRACHEA, AND BRONCHI.

With the exception of the region of the vocal cords, the free margin of the epiglottis, and a portion of the arytenoid cartilages, which are covered by stratified *pavement epithelium,* the mucous membrane of the *larynx* has stratified ciliated epithelium like that of the respiratory region of the nasal cavity and the upper portion of the pharynx. The tunica propria is unusually rich in elastic fibers, which form dense

PLATE 64.—TRACHEA.

Transverse Section of the Trachea of an Eight-year-old Boy. × 6½.

The figure gives a general picture of the structure of the trachea and of the lamination of its walls.

Technic: Müller's fluid. Hematoxylin-eosin.

Reference letters: *ep*, Epithelium; *gl*, glands; *Kn*, cartilage; *m*, muscularis; *sm*, submucosa; *tp*, tunica propria.

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networks just under the epithelium, forming the *membrana elastica*. In other respects the mucous membrane of the larynx has the same structure as that of the trachea. The *cartilages* of the larynx are partly hyaline (thyroid, cricoid), partly elastic (epiglottis), and partly mixed (arytenoid cartilages).

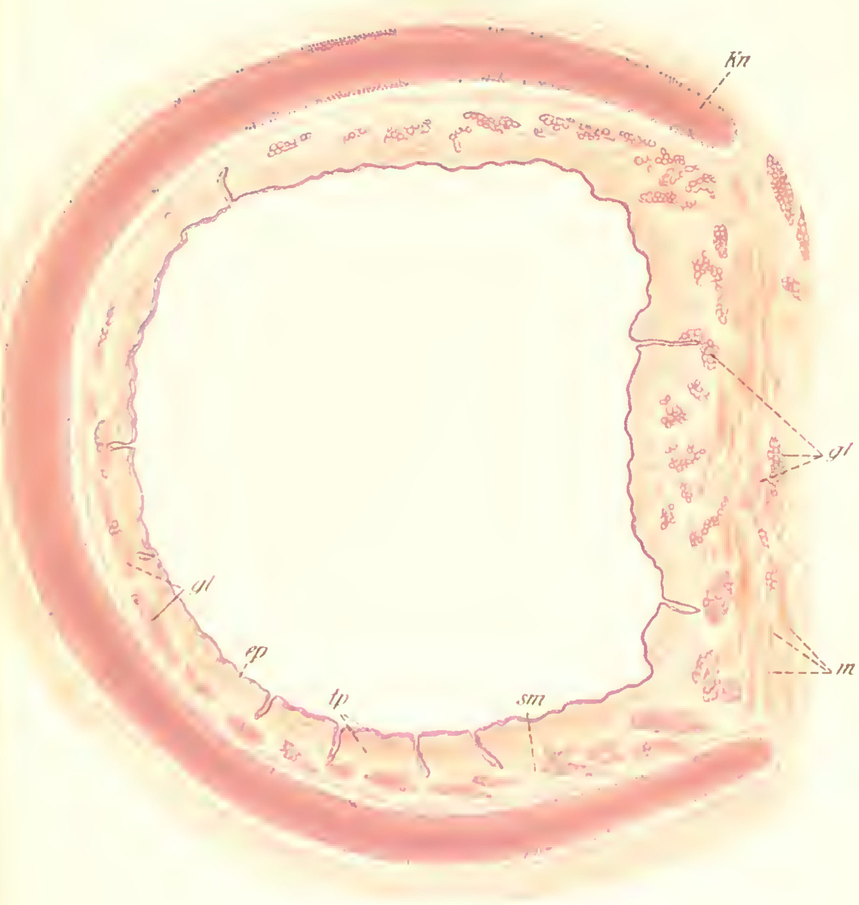
The *trachea* has a relatively thick mucous membrane, which is rich in elastic fibers. The epithelium is stratified ciliated columnar. Under the mucous membrane lies a *submucosa*, which contains branched *tubular glands* of mixed character, containing both mucous and serous cells. The outer wall in the anterior three-fourths is formed of horseshoe-shaped hoops of hyaline cartilage; in the posterior one-fourth, by non-striated muscle. The glands are best developed in the posterior wall and lie between or outside of the muscle layer.

The large *bronchi* have the same structure as the trachea, except that they contain plates instead of hoops of cartilage.

THE BRONCHIAL BRANCHES AND THE LUNGS.

The large branches of the bronchi have the same structure as the trachea and the bronchi. The structure remains essentially the same in the further branchings, with these exceptions: The cartilages of the bronchi of medium size resemble elastic cartilage and no longer form half-rings, but irregularly distributed *plates*. Cartilage plates

Tab. 64.



are found in the bronchi until their caliber is 1 mm. The non-striated *muscle* of the bronchi of medium size forms a continuous layer of circularly arranged fibers; this layer becomes thinner as the caliber of the bronchi diminishes, but can still be followed beyond the limits of the cartilage; it lies *within* the cartilage plates. Besides this, a change takes place in the epithelium of the bronchial branches, so that the stratified ciliated epithelium is gradually reduced to a single layer (see Plate 66, Fig. 1).

The bronchi which have no cartilage, under 1 mm. in caliber, are known as *bronchioles*. They still have a layer of muscle and a single layer of cubic epithelium.

The bronchioles lead into the *respiratory bronchioles* and these in turn into the terminal bronchioles or *alveolar ducts*, the smallest terminal portions of the bronchial tree, which serve partly for respiration. The terminal bronchioles are characterized by the fact that their epithelium consists of two kinds of cells: of small, round, nucleated cells, between which large, flat, non-nucleated cells are found. The latter gradually appear in the shape of islands at the point of transition from the bronchus into the respiratory portions of the lung. Each terminal bronchus opens into three to six nearly spheric spaces known as atria. Each atrium opens into a number of irregular spaces known as air-sacs. The air-sacs communicate with smaller spaces, the air-cells or alveoli. Numerous alveoli are found on the wall of the terminal bronchus. It contains a layer of non-striated muscle. This layer of muscle does not extend beyond the limits of the terminal bronchioles. The atria, air-sacs, and alveoli are lined by flat, non-nucleated cells, among which groups of small, round, nucleated cells are found. The *alveolar wall* is very thin, and, aside from the epithelium, is formed by capillaries and a very small amount of connective tissue and elastic fibers. The walls of neighboring alveoli, especially their elastic tissue, fuse to form *alveolar septa*. By means of fine openings or pores in these septa, neighboring alveoli communicate with each other.

Fig. 59.—Transverse section of a bronchiole of the human lung, from the same preparation as Fig. 1, Plate 66. × 280. The figure presents the transverse section of a small bronchial branch having simple ciliated epithelium and no cartilaginous framework; in the mucous membrane many elastic fibers are seen.

Fig. 60.—Portion of a thick cross-section of a human lung treated with silver nitrate solution. × 160. The preparation was taken from a man who had been executed.

In the preparation the cell boundaries of the epithelium are stained black by the silver. The figure shows a respiratory bronchiole in its branching from a smaller bronchial branch. The lower wall of the bronchiole is seen, still lined by cubic epithelium. This is then gradually broken up by islands of flattened cells. In the alveoli we see the typical relation of the epithelium. *A*, Alveoli; *brr*, respiratory bronchiole; *ep*, cubic epithelium; ep_1, flattened epithelial cells; *p*, carbon pigment.

The connective tissue which is present in very small amount as *interstitial* tissue penetrates the lung along the larger bronchial branches. Under the serous covering of the lungs (pleura pulmonalis) it forms a thin layer and also separates the several lobules of the lung—the lobuli pulmonales—from each other. It often contains carbon pigment which has been inspired with the air.

The *blood-vessels* of the lung arise from the pulmonary artery and the bronchial arteries. The latter supply the walls of the bronchi, sending only relatively few branches to the alveoli. The branches of the pulmonary artery follow the course of the bronchi. They branch with these and in the alveolar wall form a dense plexus of capillaries, which are especially large, so that the greatest part of the surface of the alveolar wall and of its epithelium is bounded by capillaries. The large, flat, non-nucleated cells generally cover the capillaries; the small round cells lie in the spaces between the capillaries. From the capillaries arise the radicles of the pulmonary veins.

There are large numbers of *lymph-vessels* in the lungs. They form two sets of vessels. The one is found in the interlobular connective tissue and communicates with the lymphatics of the pleura, where a rich plexus is found. The deeper set accompanies the pulmonary artery; its

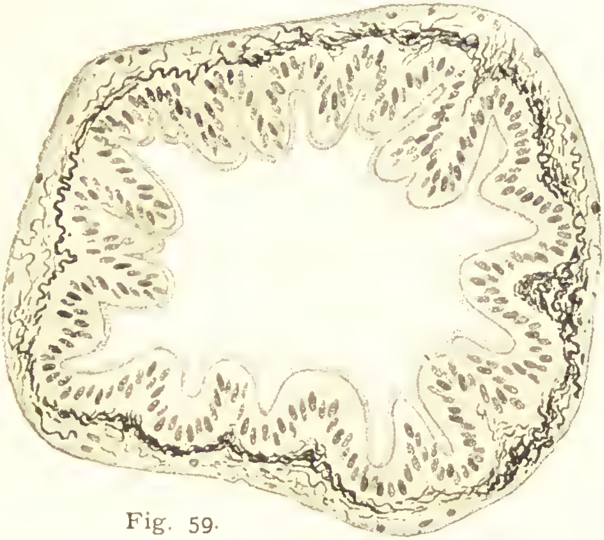


Fig. 59.

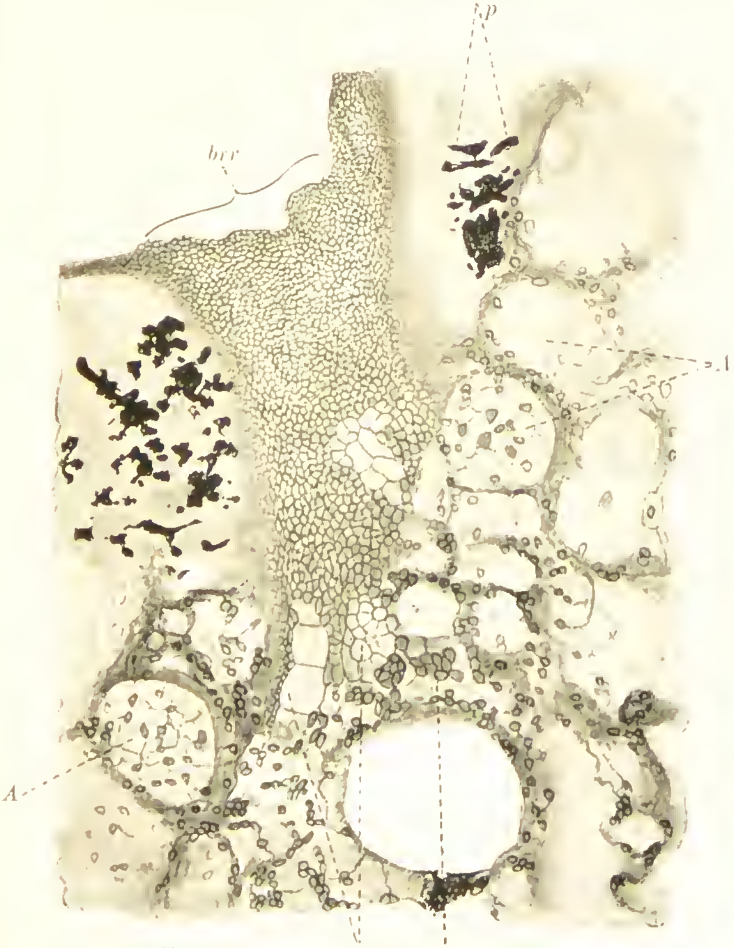


Fig. 60.

vessels pass directly to the bronchial glands. *Lymph-glands* are found at the hilus of the lung and nodules of adenoid tissue along the larger bronchi and even on the surface of the lung.

The *nerves* of the lung arise from the vagus and from the sympathetic. Their mode of ending is not fully determined. However, the final endings lie in the alveolar walls, in the epithelium of the bronchi, and in the muscle of the bronchi. Sympathetic ganglia are found in the course of the nerves.

THE THYROID GLAND.

The *thyroid* gland may be considered here, although it has only topographic relations with the respiratory system. Originally it possesses an excretory duct system and is in relation with the mouth by means of the ductus thyreoglossus. Later the duct is obliterated and the gland then consists of the closed secreting compartments or alveoli. The terminal compartments of the thyroid gland are short branched *tubules* or alveoli. They are lined by a single layer of columnar to cubic epithelium. The secretion of the tubules or alveoli, called *colloid*, often fills their lumen completely and distends the walls to such an extent that the epithelial cells lining them are flattened. The empty tubules or alveoli therefore generally present the highest epithelium. There is much evidence to show that the secretion is taken up by the numerous lymph-vessels of the gland. The thyroid contains numerous blood-vessels, which form dense capillary networks around the tubules or alveoli, likewise many lymph-vessels. Sympathetic nerve-fibers terminate on the alveoli or tubules.

X. THE SKIN.

The skin is composed genetically of two main constituents: an *epithelial tissue*, the *epidermis*, and a *connective tissue*, the *cutis*. Each of these consists of subdivisions.

PLATE 65.—LUNGS.

Portion of a Transverse Section of a Human Lung, the Blood-vessels of Which Have Been Injected with Blue Gelatin. × 100.

From material of the Würzburg Anatomical Institute.

The figure shows the cross-section of many alveoli, and in some portions the surface of the alveolar wall is met. The latter is not stained.

Reference letters: *a*, Branch of pulmonary artery; *A*, alveoli; *ca*, capillaries of alveolar wall seen from the surface; *sa*, alveolar septa, with the capillaries sectioned vertically; *ti*, interlobular interstitial connective tissue; *v*, venous branch, the vena pulmonalis.

The *epidermis* is divided into four layers named from without inward: (1) the stratum corneum; (2) the stratum lucidum; (3) the stratum granulosum; (4) the stratum germinativum.

The *stratum corneum* consists of flat, horny, non-nucleated cells, which in many places of the skin, for instance in the palm of the hand, sole of the foot, are in many layers.

PLATE 66.—LUNG, THYROID GLAND.

FIG. 1.—**Transverse Section of a Small Bronchial Branch of the Human Lung.** × 25.

The preparation was taken from a man who had been executed. Prepared by Professor Braus, of Heidelberg.

The figure shows a small bronchus together with the surrounding lung tissue. The elastic fibers are stained dark violet. The musculature of the bronchial wall is so covered by the elastic fibers that it is not visible under low magnification.

Technic: Zenker's solution. Weigert's elastic tissue stain. Alum-carmin.

Reference letters: *A*, Alveoli; *bg*, blood-vessels; *dgl*, duct of bronchial gland; *ep*, epithelium; *gl*, mucous glands; *n*, transverse section of a nerve; *tp*, tunica propria with elastic fibers; *v*, wall of a large vein of the lung; *Kn*, cartilage.

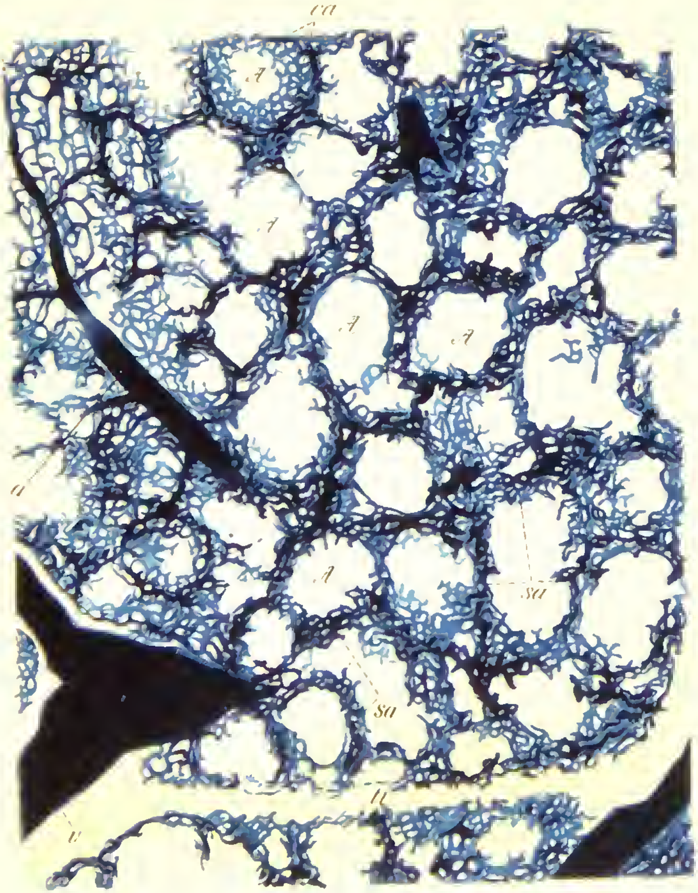
FIG. 2.—**Portion of a Cross-section of the Thyroid Gland.** × 30.

The preparation was taken from a man who had been executed.

The figure shows the gland tubules of the thyroid gland, filled to different degrees with the colloid substance.

Technic; Müller's fluid. Hematoxylin-eosin.

Reference letters: *bdg*, Interstitial connective tissue; *bg*, blood-vessels; *C*, colloid substance; *ts*, gland alveoli.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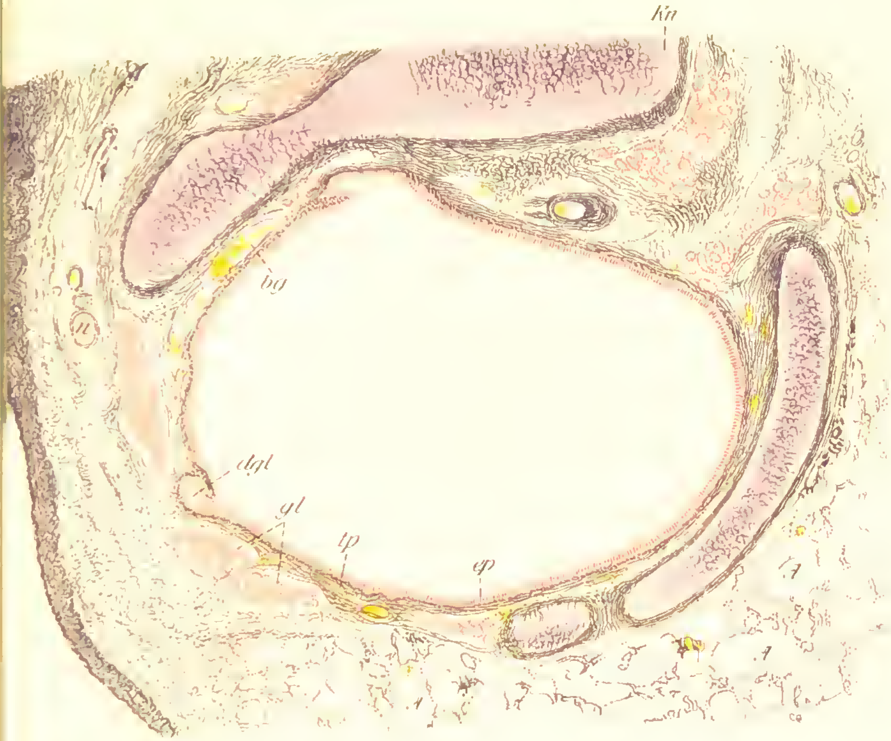

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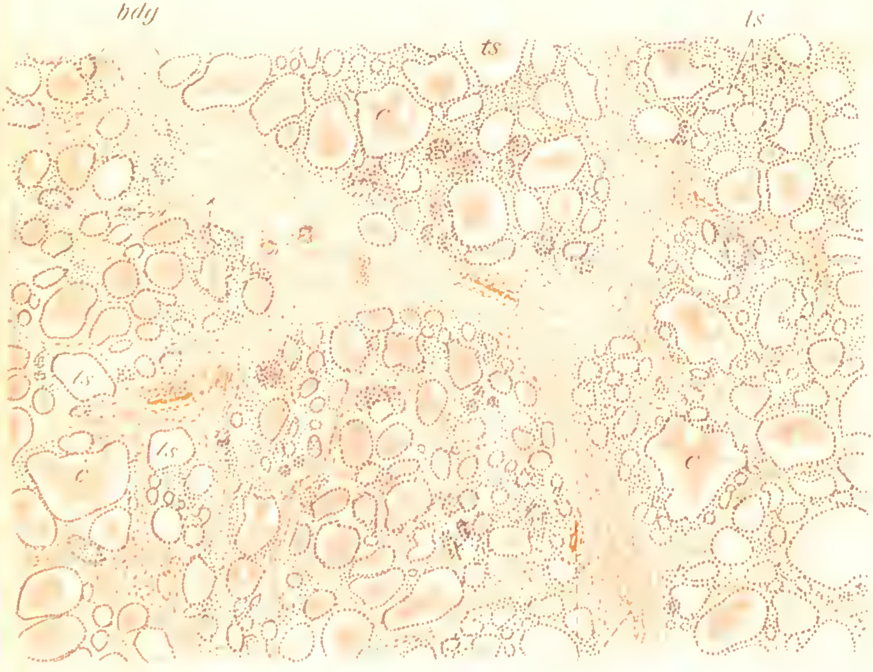

Fig. 2.

The *stratum lucidum* can be differentiated distinctly only when there is a strongly developed stratum corneum. It consists of two, or at most three layers of flat, clear cells, which are not yet completely cornified. It is not sharply separated from the stratum corneum. The *stratum granulosum* also consists of two or three layers. It is especially well developed in places in which the horny layer is well developed. Its cells are flattened polygonal and contain distinct, deeply staining granules known as keratohyalin or eleidin granules[1] of irregular form and of different size, which are to be regarded as the preliminary stages of the horny substance, the keratin. The *stratum germinativum* consists of many layers of cells, which are indented by the papillæ of the cutis, which lies below it. The cells of the lowest layer, which lies next to the papilla, are columnar, while the cells of the other layers are rounded polygonal, except the upper ones which border upon the stratum granulosum and, like the cells of this layer, are flattened. The epithelial cells of the stratum germinativum are connected by very distinct *intercellular bridges* (see page 32), and on this account it is called the *stratum spinosum* or *dentatum*. The stratum germinativum furnishes the cells for the regeneration of the external layers of the stratum corneum, which are continually being pushed off. The lowest layer of the stratum germinativum, the layer of cylindric cells, shows constant mitoses.

The connective-tissue portion of the skin, the *cutis*, is divided into two main layers, which are closely connected and which pass over into each other without any distinct line of demarcation. The *corium* borders on the epidermis and consists of formed, fibrous connective tissue, and the *tela subcutanea* is characterized by the presence of adipose tissue.

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[1] Keratohyalin and eleidin are used as synonymous terms by many authors, while by others the term eleidin is given to the unformed horny material of the stratum lucidum.

PLATE 67.—SKIN.

FIG. 1.—**Transverse Section of the Skin of the Vola Manus of Man.** × 15.

The preparation was taken from a man who had been executed.

The figure shows a general picture of the structure and lamination of the skin.

Technic: Zenker's solution. Hematoxylin-eosin.

Reference letters: *a*, Artery; C, corium; *el*, Vater-Pacinian corpuscle; *ep*, epidermis; *glsu*, sudoriferous glands; *lf*, muscle-fibers of the palmaris brevis; *pa*, panniculus adiposus; *stc*, stratum corneum; *stg*, stratum germinativum; *ts*, tela subcutanea.

FIG. 2.—**Portion of a Transverse Section of the Injected Skin of the Vola Manus.** × 15.

The figure shows the principal relations of the blood-vessels of the skin.

Technic: Injection with Berlin blue gelatin. Müller's fluid. Borax-carmin.

Reference letters: *C*, Corium; *gls*, sudoriferous glands; *p*, papillæ; *strc*, stratum corneum of the epidermis; *strg*, stratum germinativum of the epidermis; *ts*, tela subcutanea.

PLATE 68.—SKIN, HAIR.

FIG. 1.—**Portion of the Transverse Section of the Skin of the Vola Manus of Man.** × 170.

The preparation was taken from a man who had been executed.

The figure shows the structure of the different layers of the epidermis and of the upper portion (stratum papillare) of the corium.

Technic: Zenker's solution. Hematoxylin-eosin.

Reference letters: *bg*, Blood-vessels of corium; *C*, corium; *ds*, excretory duct of a sweat-gland; *ep*, epidermis; *n*, nerve, entering a tactile corpuscle; *stc*, stratum corneum of the epidermis; *stg*, stratum germinativum; *stgr*, stratum granulosum; *stl*, stratum lucidum; *tk*, tactile corpuscle.

FIG. 2.—**Single Cells of the Stratum Germinativum of the Preparation in Fig. 1.** × 700.

The figure shows the intercellular bridges.

FIG. 3.—**Lower Portion of a Longitudinal Section of the Root of the Hair from the Human Scalp.** × 100.

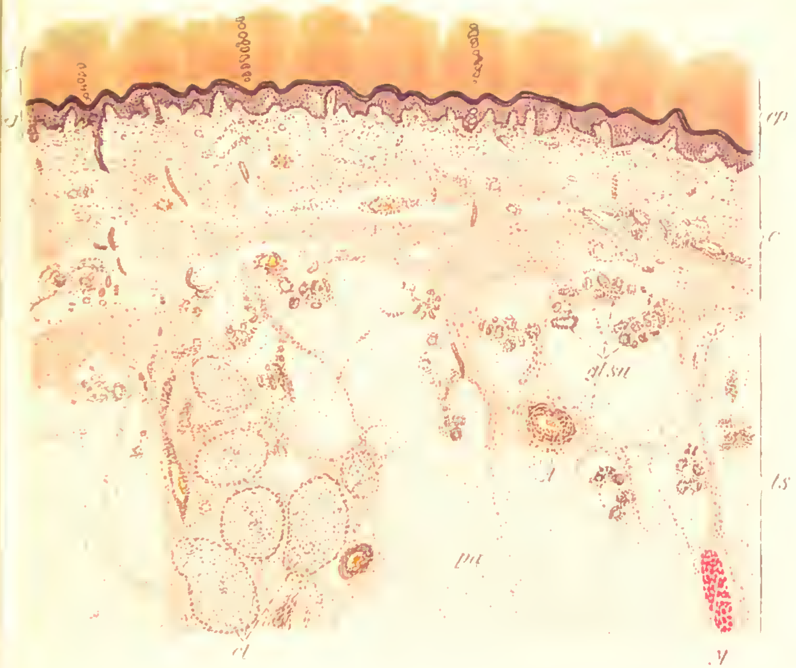
The preparation was taken from a man who had been executed.

The figure shows the relation of the different layers of the hair and its root-sheaths in the region of the bulb of the hair.

Technic: Zenker's solution. Hematoxylin-eosin.

Reference letters: *aw*, External root-sheath; *c*, cuticle of hair; *fp*, sheath of hair; *gl*, glassy membrane; *iw*, inner root-sheath; *P*, hair papilla; *sc*, cortical substance of hair; *sep*, hair-shaft; *sm*, medulla of hair.

Tab. 67.



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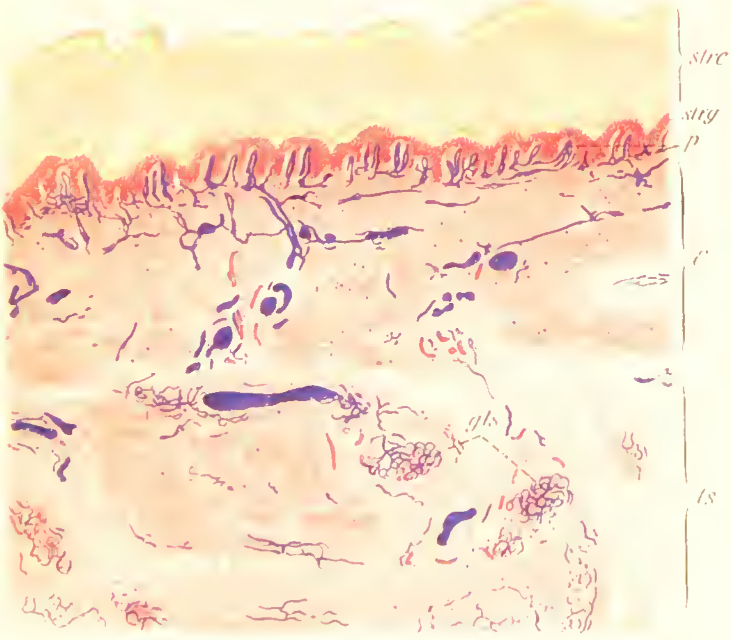

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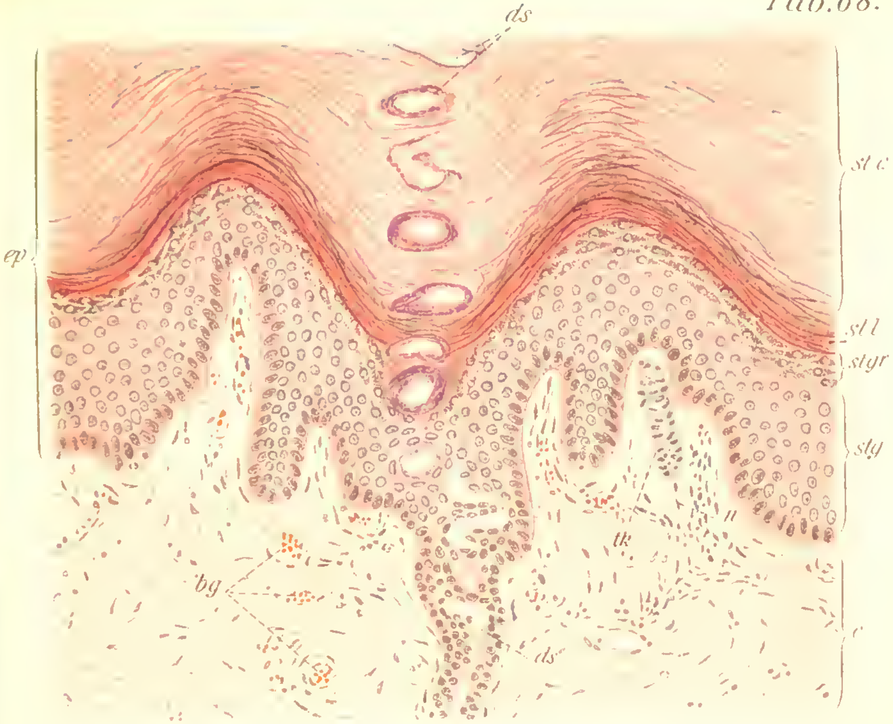

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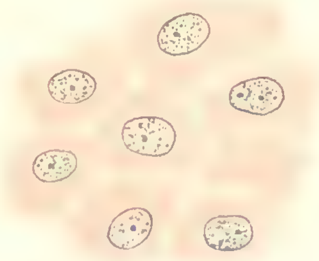

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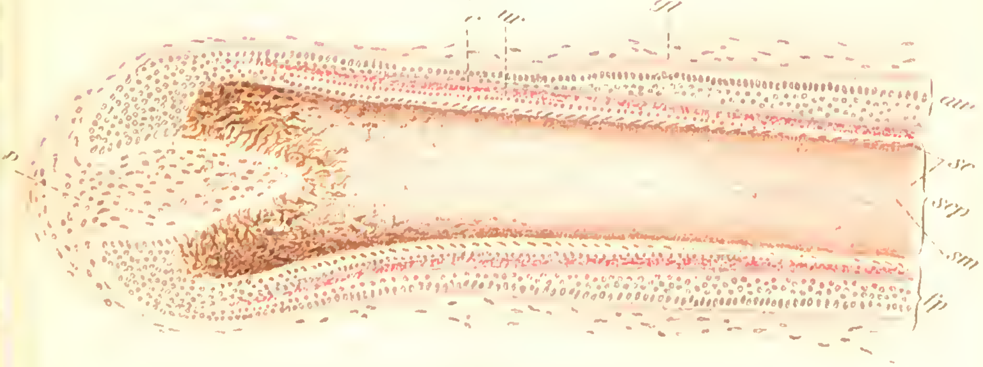

Fig. 3.

The *corium* is again divided into the *stratum papillare*, which bears the papillæ, and the deeper *stratum reticulare*. These two layers also have no sharp line of demarcation between them. The corium is composed essentially of dense connective tissue, the bundles of which cross and interlace in all directions. The stratum reticulare, in which the bundles are large and compactly interlaced, is poor in cells, but rich in elastic fibers. The cells of the corium are found between the bundles of connective tissue and are consequently of flattened shape and have elongated nuclei. The cutis also contains non-striated muscle, especially in the neighborhood of the hair, but occasionally also independently of the hair, as in the tunica dartos of the scrotum and in the region of the nipple.

The subcutaneous layer consists of strands of formed connective tissue surrounding fat-lobules.

THE EPIDERMAL STRUCTURES OF THE SKIN.

Special structures originating from the epidermis are contained in the three main layers of the skin. These are hairs, nails, and glands.

The Hair.

The *hairs* are long, thread-like, horny structures, which project beyond the surface of the skin. They are embedded in an epithelial sheath of epidermal origin, which is surrounded by a connective-tissue sheath from the corium. The portion of the hair within the skin is known as the *root* of the hair; the free projecting portion, as the *hair-shaft*. The hair-root ends in the hair-bulb. The latter is invaginated by a vascular *connective-tissue papilla* and lies, especially in the larger hairs, in the subcutaneous layer, while the hair-root lies partly in this and partly in the corium. The epidermal sheath of the hair-root is designated as the *root-sheath*; the connective-tissue sheath,

PLATE 69.—HAIR.

Transverse Section of the Human Scalp. × 15.

The preparation was taken from a man who had been executed.

The figure is composed of parts of three sections. It shows a row of hairs in longitudinal section, with sebaceous glands and Mm. arrectores, club-hairs in different stages of degeneration, young hairs, and new formation of hair.

Technic: Müller's fluid. Hematoxylin-eosin.

Reference letters: *Ap*, Musculus arrector pili; *c*, corium; *ep*, epidermis; *fp*, hair follicle; *Gap*, aponeurosis; *gls*, sudoriferous gland; *glsc*, sebaceous glands; *KH*, club-hairs; *pp*, papilla of hair; *Rc*, retinacula cutis; *Rp*, root of hair; *Sp*, shaft of hair; *ts*, subcutaneous layer; x, new formation of hair.

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as the *hair-sheath*. The structure of the hair and its sheaths can be best recognized in the larger hairs of the body.

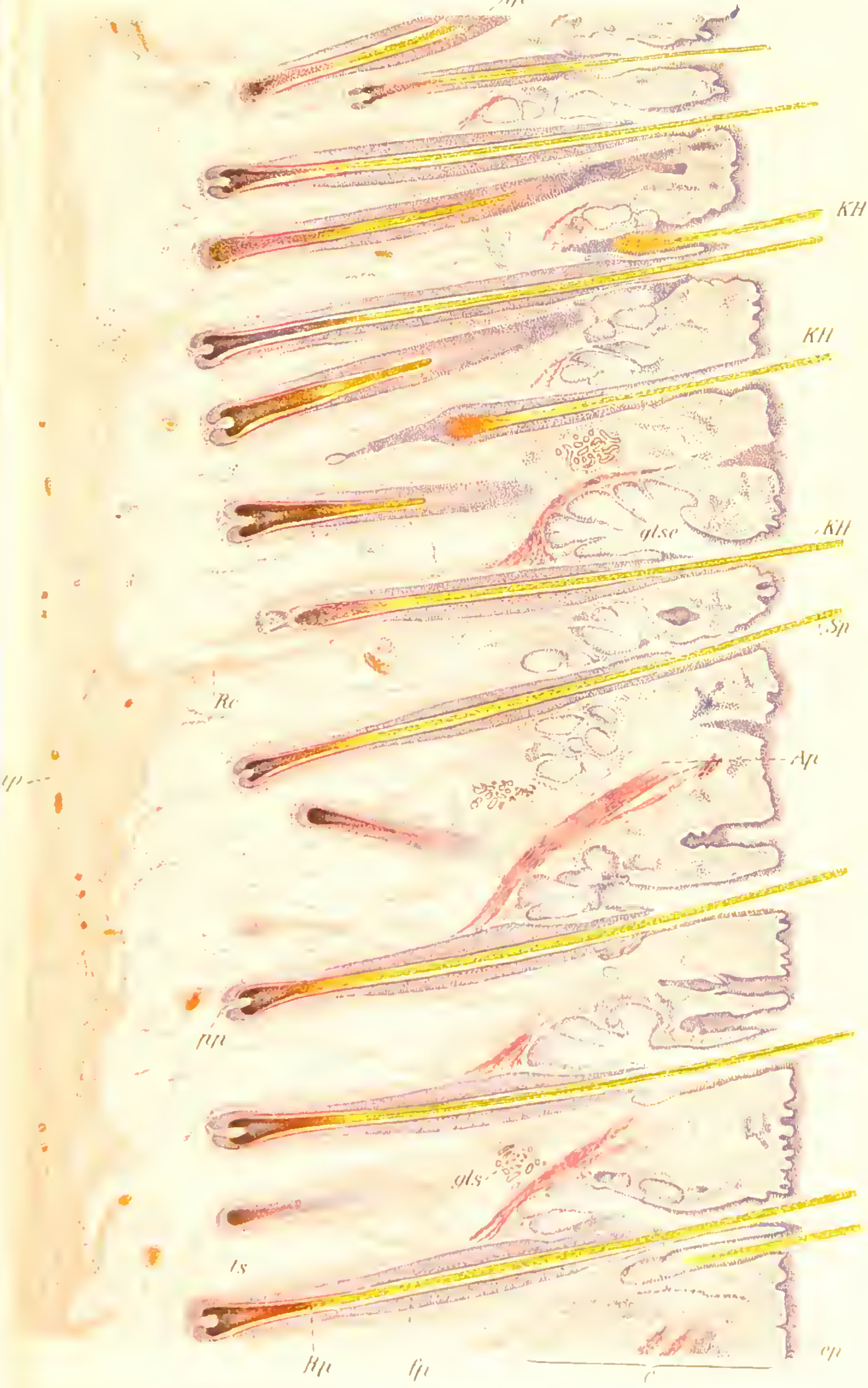
The *hair-shaft* consists of two main substances, the cortical cells and the medullary cells. The latter may be lacking. In the lower portion of the hair-root the cuticula is added to these. The *cortical cells* form the main mass of the hair. They are long, spindle-shaped cells, somewhat longer in the upper than in the lower part of the shaft of the hair-root, and contain a diffuse and granular pigment, which gives the color to the hair. They possess elongated nuclei, which are often indistinct in the free part of the hair-shaft, and somewhat shorter—that is, more oval in the lower part of the hair-root.

The *medulla* of the hair, which is not always present, forms the central portion of the hair-shaft, and is composed of quite large, polygonal, unpigmented, nucleated cells, arranged in two or three rows.

The *cuticula* of the hair is composed of flattened cells arranged like tiles. These cells are nucleated in the lower part of the root, then lose their nuclei, and finally disappear in the upper part of the root.

The *root-sheath* of the hair consists of two parts, the so-called inner and outer root-sheaths. The hair itself corresponds to the stratum corneum of the epidermis; the inner root-sheath shows the structure of the stratum luci-

Tab. 69.



dum and granulosum; the outer, that of the stratum germinativum. The *inner root-sheath* consists of two to three distinct layers: of the sheath cuticle, bordering upon the hair cuticle, distinct only in the lower part of the root; of the inner Huxley's and the outer Henle's layers. The *sheath cuticle* presents essentially the same structure as the hair cuticle. *Huxley's layer* consists of cubic to low cylindric cells in a single layer; these in the lower portion of the hair-root contain numerous keratohyalin granules. *Henle's sheath* is composed of flattened cells, which are nearly always non-nucleated. Only in the lowest portion of the hair-root do the cells of Henle's layers contain eleidin granules. In the upper portion of the hair-root the inner root-sheath is cornified. The *outer root-sheath* shows the structure of the stratum germinativum of the epidermis. It consists of a varying number of layers of cells, fewer in the lower than in the upper portion of the hair-root, the outer of which have a columnar form, the middle polygonal, and the inner—that is, toward the inner root-sheath—a flattened form. Where the hair passes through the epidermis, the outer root-sheath joins with the stratum germinativum of the epidermis without any sharp line of demarcation. Like the cells of the stratum germinativum, the cells of the outer root-sheath show mitoses.

The connective-tissue portion of the hair, the *hair-sheath*, consists of a relatively thick, structureless, and non-nucleated membrane, the so-called *glassy membrane;* external to this are two layers of connective-tissue fibers, an *inner circular* and an *outer longitudinal.* Both, circular as well as longitudinal, layers are free from elastic fibers. At the base of the hair-bulb, at the neck of the papilla of the hair, the elements of the root-sheath which here border on the papilla do not present the lamination found in the other portions of the hair follicle, as here the cells of all the layers of the root-sheaths become nucleated and form a common indifferent mass of cells bordering upon the lower portion of the papilla. This mass of polygonal cells continues to

PLATE 70.—HAIR.

FIG. 1.—**Transverse Section through the Middle Portion of a Hair-root of the Human Scalp.** × 120.

The preparation was taken from a man who was executed.

The figure shows the hair, root-sheaths, and hair-bulb. The section of the hair shows the medulla, which is stained red, and the cortical cells.

Technic: Müller's fluid. Hematoxylin-eosin.

Reference letters for Figs. 1 and 2: *aw*, External root-sheaths; *bg*, blood-vessels; *c*, cuticle of hair and of root-sheath; *gl*, glassy membrane; *hbl*, longitudinal fibers of hair-sheath; *hbr*, circular fibers of hair-sheath; *iw*, inner root-sheath; *1*, Huxley's layer of the inner root-sheath; *2*, Henle's layer of the inner root-sheath.

FIG. 2.—**Transverse Section of the Lower Part of a Hair-root from the Human Scalp.** × 300.

The figure shows relatively thin external root-sheaths; the Huxley's layer of the inner root-sheath contains numerous eleidin granules. Between it and the hair we see the cells of the cuticulæ. The hair itself has only cortical cells.

Technic and lettering the same as in Fig. 1.

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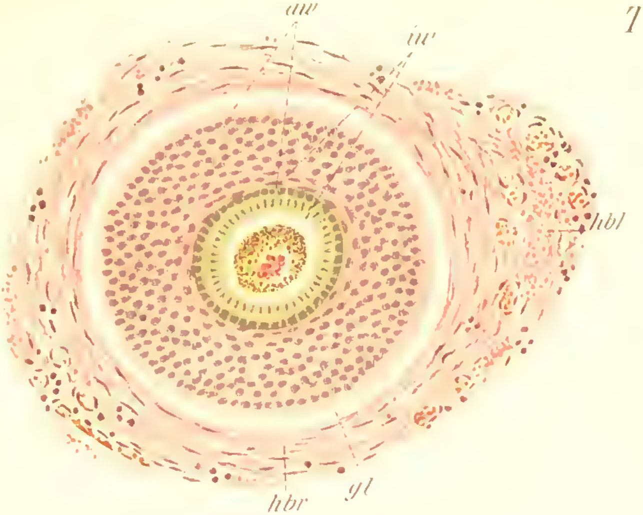
the upper part of the papilla where the hair-shaft approaches the upper end of the papilla. Toward the surface of the papilla the cells assume a columnar shape. At the upper end of the papilla the indifferent cells of the hair-bulb are mingled with intensely pigmented, peculiarly branched cells. Mitotically dividing cells are uniformly found in the cells of the hair-bulb and also in the outer layers of the outer root-sheath. The shedding of hair is a continuous process in man and does not occur periodically as in the majority of mammals. In hairs to be shed the pigmented portion of the hair-bulb cornifies. Such hairs no longer have the power of growth and are gradually pushed out of the root-sheath. Such degenerating hairs are known as *club-hairs*. They are met with in normal scalps in all stages of degeneration. In this process of degeneration the hair papilla remains and on the old papilla a new hair is formed from the cells of the outer root-sheath and from those of the indifferent matrix at the base of the root. The hair may also be replaced in the adult in the same way as the hair is formed in embryonic life—that is, by the ingrowth of a process from the

Tab. 70.



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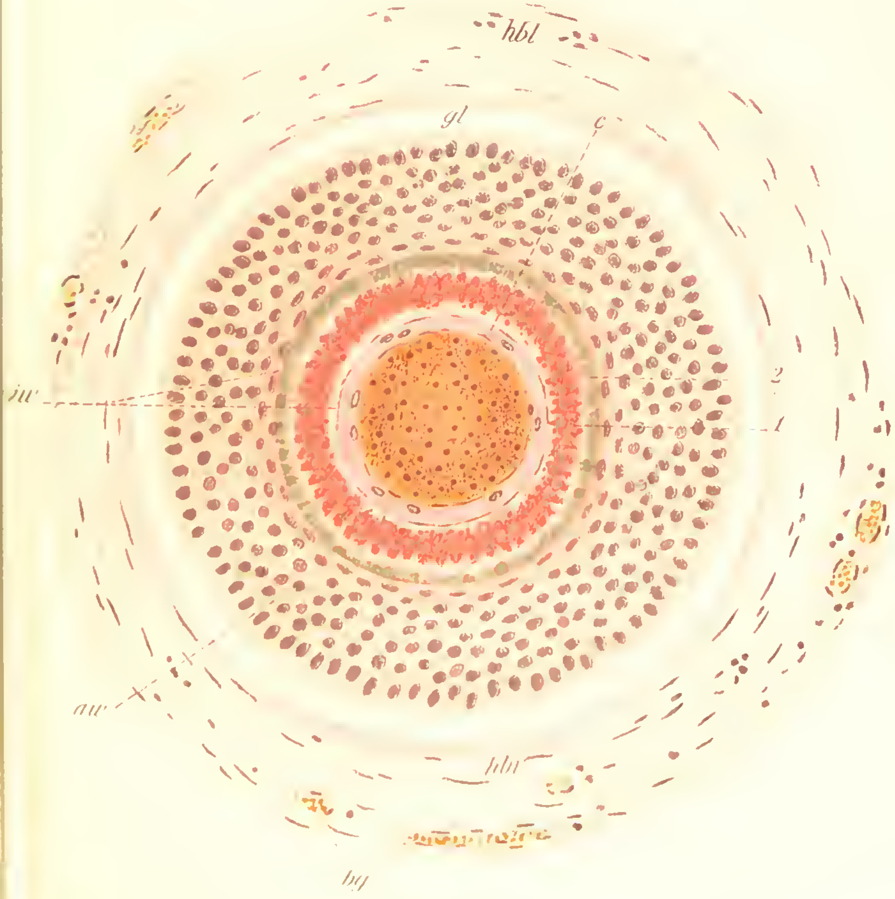

Fig. 2.

epidermis; from this the different parts of the hair are differentiated, in a similar manner as in the embryo; that is, from the axis of the hair anlage is developed the hair-shaft, and from the peripheral cells the root-sheaths. The sebaceous glands develop as epithelial buds from the ectodermal portion of the hair follicle, the hair-sheath from the surrounding connective tissue.

In the corium non-striated muscle-fibers are constantly found in connection with the larger hairs of the scalp; these are called *arrectores pilorum;* they arise from the uppermost layers of the cutis, close under the papilla, often by several roots, pass obliquely toward the hair-shaft, into which they are inserted. At the point of insertion there is a protuberance of the latter and with it of the outer root-sheath. The arrector muscle usually forms an acute angle with the hair; the sebaceous gland lies in this angle, so that the muscle also acts as an *expressor sebi.*

The Nails.

The *nails* are horny epidermal plates, the cells of which, though still nucleated, are no longer capable of division. The nail lies on the so-called nail-bed, from which it is sharply separated; the latter consists of the deeper layers of the epidermis. The proximal portion of the nail extends into the *nail-furrow* and it is surrounded by the *nail-wall.* Nail-wall and furrow are parts of the skin. The horny layer of the nail-wall, which overlaps the nail, is known as the eponychium. (See Plate 72.)

The *nail-bed* is the matrix for the growth of the nail, the anterior part for the growth in thickness of the nail, the posterior caring for the growth in length. The nail-bed is formed from the stratum germinativum of the epidermis; a stratum granulosum is lacking here and thus also the keratohyalin or eleidin granules, such as are found in the cornification of the skin and hair. The corium has no papillæ under the stratum germinativum of the nail,

PLATE 71.—HAIR, SUDORIFEROUS GLANDS.

FIG. 1.—**Portion of a Tangential Section of the Human Scalp.** × 20.

The preparation was taken from a man who had been executed.

The figure shows the grouping of the hairs, together with the muscle and glands belonging to them. The section goes through the upper portion of the hair-root.

Technic: Müller's fluid. Hematoxylin-eosin.

Reference letters: *Ap*, Arrectores pilorum; *fp*, hair-sheath; *glse*, sebaceous gland; *glsu*, sudoriferous gland; **x**, empty hair-sheath.

FIG. 2.—**Transverse Section of the Coil of a Sweat-gland of the Axillary Space.** × 50.

The preparation was taken from a man who had been executed.

The figure gives a picture of the large sudoriferous glands of the axilla, lined with high epithelium.

Technic: Zenker's solution. Hematoxylin-eosin.

Reference letters for Figs. 2-4: *ep*, Epithelial cells; *L*, lumen; *m*, smooth muscle; *mp*, membrana propria; *n*, nuclei of smooth muscle-fibers; *S*, drops of secretion; **x**, tubules cut tangentially.

FIG. 3.—**Transverse Section of a Tubule of a Sweat-gland of the Axilla, Lined with Very High Epithelium.** × 160.

The figure shows a portion of the canal with very distinct membrana propria. Between this and the epithelium we find smooth muscle-fibers.

FIG. 4.—**A Portion of a Tubule of a Sweat-gland of the Axilla Cut Tangentially.** × 160.

We see the subepithelial smooth muscle-fibers from the surface.

FIG. 5.—**Sudoriferous Glands of the Human Scalp (from a Thick Section).** × 45.

Technic: Müller's fluid. Hematoxylin-eosin.

Reference letters: *es*, Gland-coil; *ds*, excretory duct; *ps*, place of opening.

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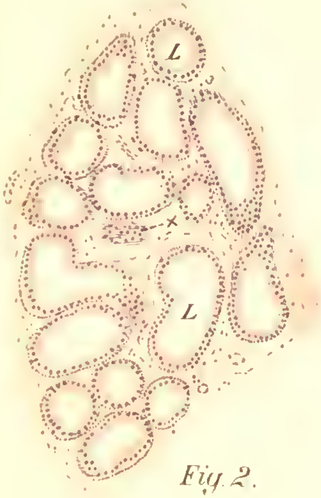
except a few under the posterior nail-furrow, but many high *longitudinal ridges* rich in capillaries.

The Glands of the Skin.

The *glands of the skin* are divided into two classes—sebaceous glands, or hair-sheath glands, and sweat-glands, or sudoriferous glands. The *sebaceous glands* occur in connection with the larger and smaller hairs; they always lie in the upper layer of the corium. In certain regions of the body they are found independent of hairs, as for instance in the labia minora. They represent glands hav-

Tab.11.



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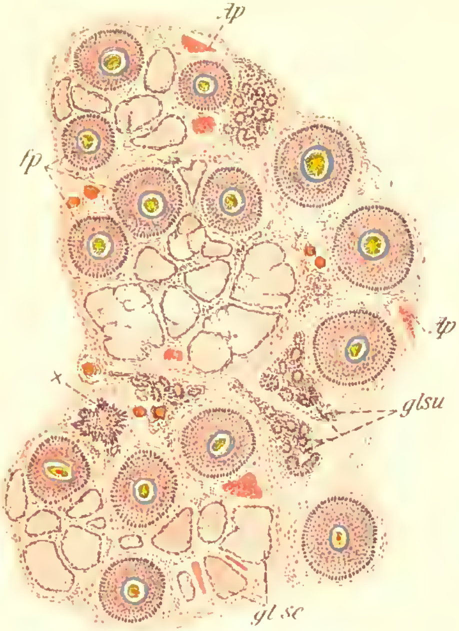

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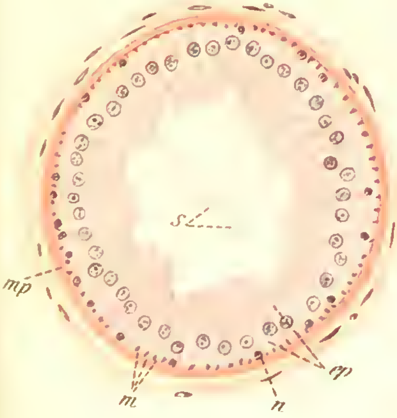

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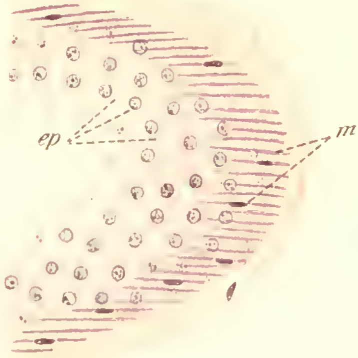

Fig. 4.

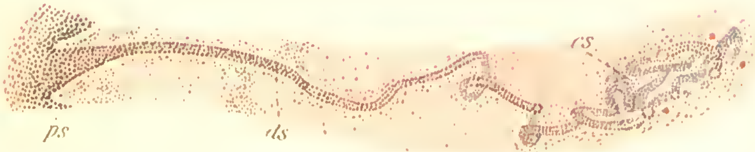

Fig. 5.

ing few *alveoli*, the wide excretory ducts of which open beside the hairs or around the smaller hairs.

The gland alveoli have no real lumen, but are quite filled with the gland-cells. At the periphery of the alveolus the latter are cubic and small, but they become larger and larger toward the interior of the alveolus by the formation of drops of secretion in the protoplasm. With the increase in the quantity of the secretion, the sebum, the nucleus of the cell shrinks and degenerates. The elements lying in the center of the alveolus consist of a collection of drops of secretion arising from the cells, without nuclei. The excretory duct of the sebaceous gland is lined by stratified pavement epithelium like the epidermis and passes immediately into this at the point of exit.

The *sudoriferous glands* of the skin are long tubular glands much coiled at the blind end. The coil, at least of the larger glands, lies in the tela subcutanea, the excretory duct breaking through the corium and all the layers of the epidermis. The coil of the *larger sweat-glands*, especially the *axillary glands*, shows a high, often columnar epithelium, followed by a layer of smooth muscle-fibers and then a thick membrana propria. The coils of the larger sweat-glands have a large lumen. The median and smaller sweat-glands have coils of essentially the same structure, except that they have a narrower lumen, lower epithelium, and often a less distinct layer of smooth muscle. The excretory duct of the sweat-gland is lined with cubic epithelium and passes through the corium nearly straight or a little winding. The cells of the duct fuse with those of the stratum germinativum of the epidermis. In the epidermis the duct of the sweat-glands shows marked windings, which have a corkscrew arrangement in the stratum corneum and there have no walls of their own. They open into the porus suduriferus.

The blood-vessels of the skin lie in the dermis; the larger branches in the tela subcutanea, the smaller branches in the corium. They are characterized by rich anasto-

PLATE 72.—SEBACEOUS GLANDS, NAIL.

FIG. 1.—**Portion of a Cross-section through a Sebaceous Gland of the Human Ala Nasi.** × 280.

The preparation was taken from a man who had been executed.

The figure shows the cells of the sebaceous gland in the different stages of secretion.

Technic: Müller's fluid. Hematoxylin-eosin.

Reference letters: *k*, Unchanged cell nuclei; k_1, much shrunken nuclei; *Rz*, border cells; *Sz*, cells filled with secretion.

FIG. 2.—**Transverse Section of the Nail of a Two-year-old Child.** × 20.

The figure shows about two-thirds of the entire cross-section and gives a general picture of the relation of nail-plate, of nail-furrow, and of nail-wall.

Preparation from the collection of the Institute of Comparative Anatomy of Würzburg.

Reference letters for Figs. 2 and 3: *bg*, Blood-vessels of nail-bed; *c*, corium of nail-bed with the nail-furrows; *epo*, eponychium; *glsu*, sudoriferous glands; *N*, nail-plate; *Nb*, stratum germinativum of nail-bed; *Nf*, nail-furrow; *Nw*, nail-wall; *P*, papillæ.

FIG. 3.—**Posterior Portion of a Longitudinal Section of the Nail of a New-born Child.** × 25.

The figure shows the papillæ of the nail matrix.

Technic: Müller's fluid. Hematoxylin-eosin.

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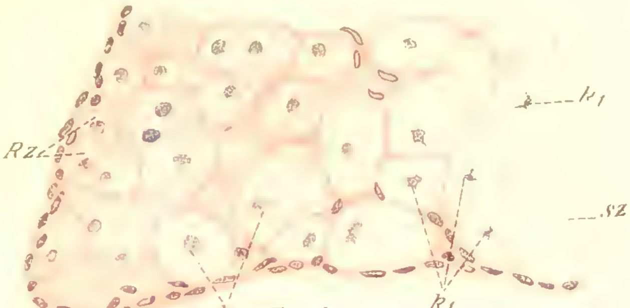
moses; thick capillary networks surround the fat-lobules of the tela subcutanea and the coils of the sweat-glands; moreover, capillary networks lie in the papillæ of the corium, where they approach close to the epidermis and into the hair papillæ. The outer layer, the longitudinal layer of fibers of the hair-sheath, contains capillaries. The veins form superficial networks in the deeper portions of the corium. The lymph-vessels of the skin are found abundantly in the region of the papillæ and in the tela subcutanea.

The *nerves* of the skin are almost exclusively sensory. Motor nerves, the neuraxes of sympathetic neurones, pass to the arrectores pilorum, as well as to the non-striated muscle of the blood-vessels. The sensory nerves penetrate into the stratum germinativum of the *epidermis*, terminating either as free sensory endings or in telodendria with tactile discs. Other sensory nerves terminate in the Meissner's corpuscles found in certain papillæ of the



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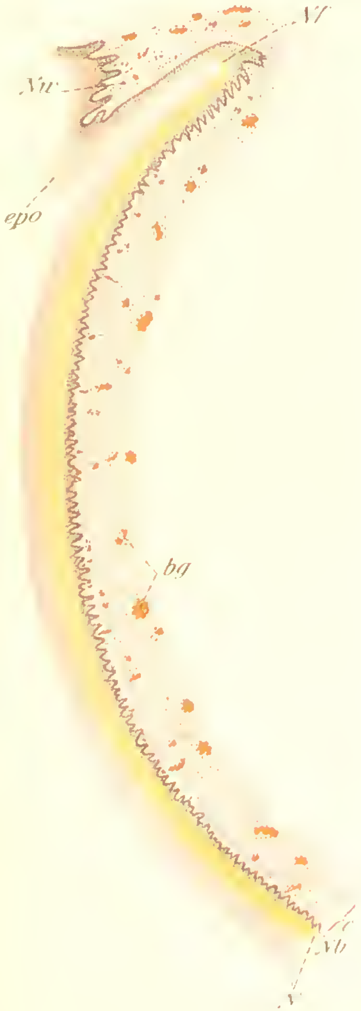


Fig. 2.

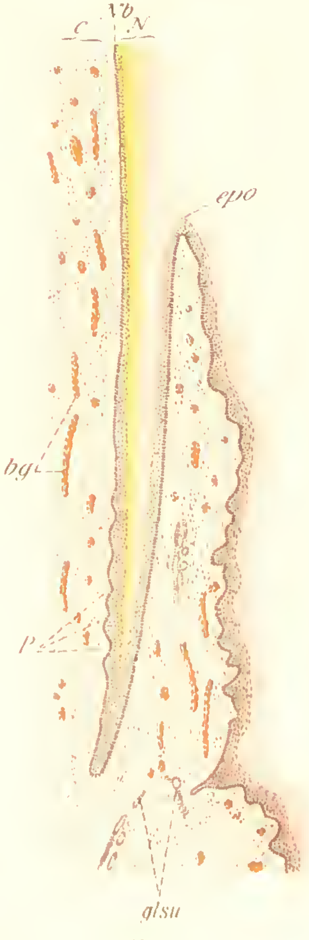


Fig. 3.

corium, or in the Pacinian corpuscles situated in the subcutaneous layer.

The Mammary Gland.

The *mammary gland* is a large skin-gland of *alveolar* character, or rather it is a collection of about fifteen smaller glands, which represent modified sweat-glands. Connective tissue surrounds the collection of glands and makes them appear like one gland. Each single gland corresponds to the lobe of the entire mammary gland and represents a compound alveolar gland. The excretory duct of the mammary gland presents an enlargement, the *sinus lactiferus*, a short distance before it opens on the nipple. The secreting *alveoli* are lined by cubic to columnar epithelium, which, however, varies according to the stage of secretion ; after evacuation of the secretion it is almost flat. The secretion of the cells of the mammary gland can be easily recognized, because, in addition to a fluid, albuminous (casein) secretion, a solid substance (fat-drops) is secreted. The fat-drops develop as small droplets in the side of the cell turned toward the lumen, increase in size, and finally are separated from it by a thin border of protoplasm. This is finally broken through and the fat-drops reach the lumen. The empty cell then appears low, often with flattened nucleus, as the fat-drop, as long as it remains in the protoplasm of the cell, presses the nucleus toward the wall. After the evacuation of the fat-drop the cell again increases in height and may again secrete milk (fat-drops). The alveoli of the mammary gland are quite large and have a relatively large lumen.

The excretory duct is lined by cubic and in places by a flattened epithelium. The *blood-vessels* form networks around the gland alveoli. Lymph-vessels are abundant. Their contents flow toward the glands of the axilla.

The mammary gland has a rich nerve-supply, consisting mainly of the neuraxes of sympathetic neurones, which end in terminal branches on the secretory cells.

PLATE 73.—MAMMARY GLANDS.

FIG. 1.—**Transverse Section of a Lobule of the Human Mammary Gland at the Time of Lactation.** × 50.

The material of this preparation was secured by operation.

The figure shows a part of a lobule of the mammary gland with a larger excretory duct. Connective-tissue trabeculæ separate the several lobules.

Technic: Sublimate. Hematoxylin-eosin.

Reference letters: *ds*, Excretory duct; *sl*, sinus lactiferus; *ti*, interstitial, interlobular connective tissue; *ts*, secreting alveoli.

FIG. 2.—**A Portion of the Above Section; Two Mammary Gland Alveoli More Highly Magnified.** × 420.

The figure shows two secreting alveoli. The glandular epithelium is partly cylindric without drops of secretion; the drops of secretion appear clear, because they consist of fat, which was removed by treatment of the preparation; for the most part the cells contain larger or smaller fat-drops, but partly (at **x**) the secretion has been evacuated and the cell is flat.

FIG. 3.—**Transverse Section through Three Alveoli of the Mammary Gland of a Nursing Mouse.** × 420.

The figure shows essentially the same as Fig. 2, only the drops of secretion (fat) are blackened by osmic acid and are still visible after the evacuation of the secretion into the lumen of the canal.

Technic: Flemming's solution. Safranin.

Reference letters: *L*, Lumen; *s*, drops of secretion before evacuation; s_1, drops of secretion after evacuation.

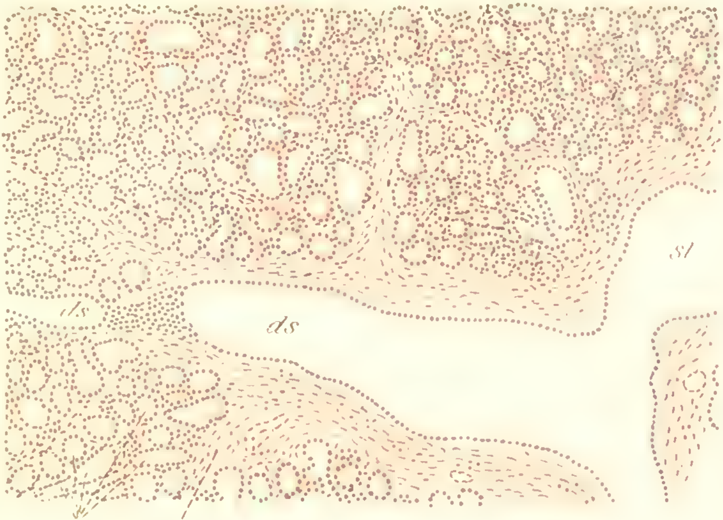
XI. THE SPECIAL SENSE ORGANS.

THE ORGAN OF VISION.

Under the *organ of vision* we need to consider the eyeball, bulbus oculi, and its auxiliary apparatus, including the eyelids and conjunctiva, the lachrymal apparatus, and the motor apparatus of the eye—that is, muscles, tendons, and fasciæ. The eyeball represents a quite regularly formed hollow sphere, the contents of which are for the most part fluid or nearly fluid. At the anterior part of the sphere is a segment of another sphere of smaller radius.

The wall of the eyeball is formed by three tunics, the sclera or tunica externa, the choroid or tunica media, also

Tab.73.



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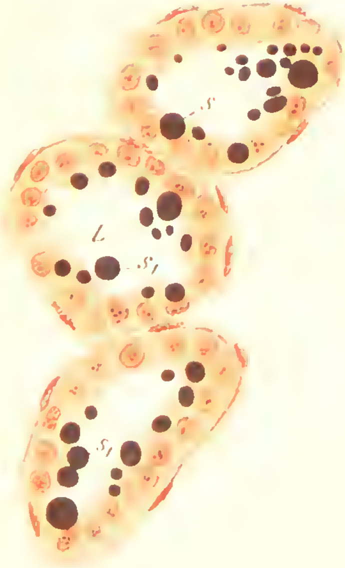

Fig. 3.

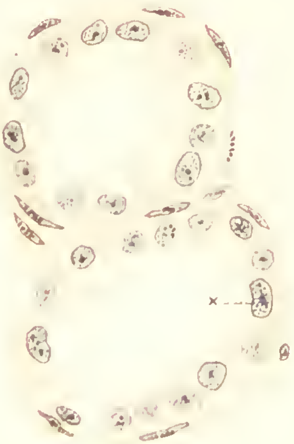

Fig. 2.

known as the uvea, and the retina or tunica interna. The anterior segment is bounded by only *one* tunic, the tunica externa or cornea.

The iris, which may be regarded as a septum containing an opening in its center and representing the forward continuation of the choroid or middle tunic of the eye, divides the cavity of the eyeball into a larger posterior chamber and a smaller anterior chamber. The opening of the iris, known as the pupil, incloses a biconvex body, the lens, which is situated in the anterior portion of the posterior chamber of the eye. The space behind the lens is for the most part filled by the vitreous body, the superficial layer of which thickens in the anterior part to form the zonula ciliaris.

The space between the iris and cornea is known as the anterior chamber of the eye. The optic nerve enters the posterior surface of the bulb, nearer to the nasal than to the temporal side.

The Sclera or Tunica Externa.

The anterior transparent portion of the external tunic, the *cornea*, consists mainly of formed connective tissue, the bundles of which are arranged very regularly in lamellæ. The epithelium of the cornea is on the surface of this connective tissue. In descriptions of the cornea we usually distinguish five layers, which are as follows, named from the anterior portion posteriorly: (1) The epithelium; (2) the anterior elastic membrane or Bowman's membrane; (3) the substantia propria of the cornea; (4) the posterior basal elastic membrane or Descemet's membrane; (5) the endothelium of the anterior chamber. The *epithelium* of the cornea passes over at the edge of the cornea into the epithelium of the conjunctiva. Like this it is a stratified pavement epithelium, but has no papillæ and only a few layers of the flattened cells. The *anterior* and *posterior elastic membranes* are non-nucleated, especially differentiated lamellæ of the substantia propria. The

PLATE 74.—THE EYE.

Horizontal Section through the Human Eyeball. × 4.

The preparation was taken from a man who had been executed.

The figure gives a general picture of the entire bulb, with the place of entrance of the optic nerve, and the fovea centralis, in which regions the figure is slightly diagrammatic.

Technic: Chromic acid solution, 2 per cent. Hematoxylin-eosin.

Reference letters: *C*, Cornea; *co*, conjunctiva; *coa*, anterior chamber of the eye, camera oculi anterior; *cop*, posterior chamber of the eye, camera oculi posterior; *fc*, fovea centralis retinæ; *I*, iris; *imr*, insertion of the rectus muscle; *L*, lens; *mc*, ciliary muscle in the ciliary body; *no*, optic nerve; *os*, ora serrata; *p*, papilla of optic nerve; *Sc*, sclera; *Zc*, zonula ciliaris.

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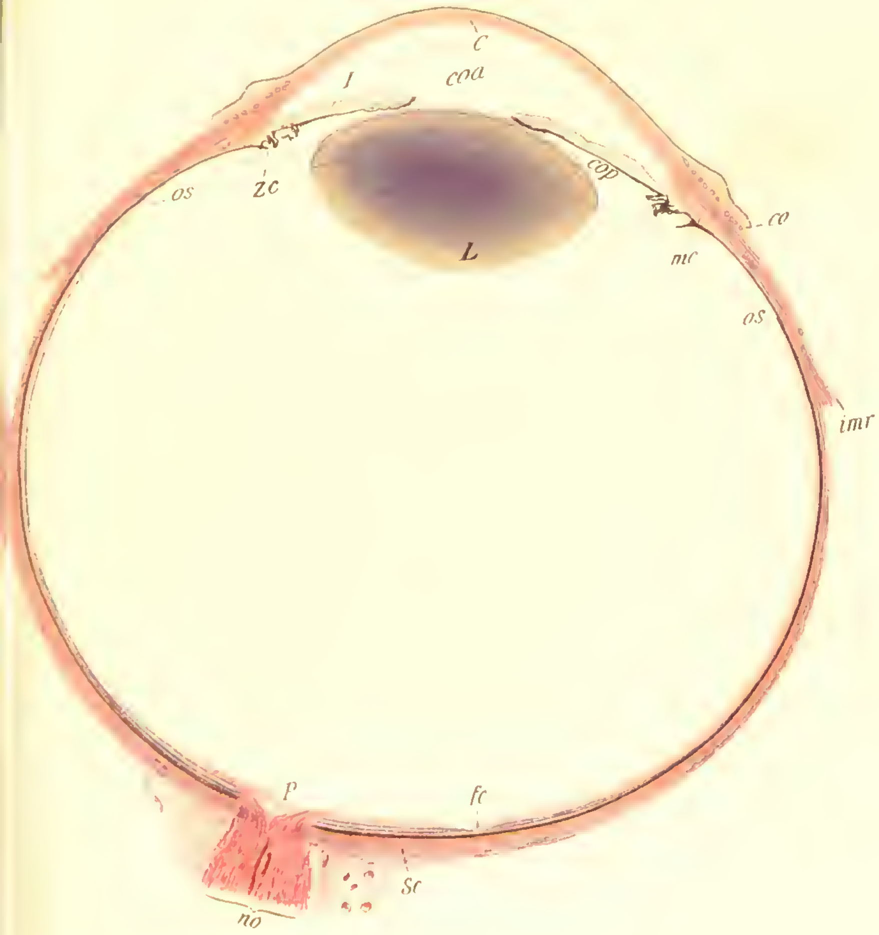
substantia propria of the cornea consists entirely of connective tissue and has very distinct and very regularly arranged parallel lamellæ, between which the *corneal corpuscles* are placed. The lamellæ themselves consist of firmly cemented bundles.

The *corneal cells* are large, well-developed connective-tissue cells with lamellar processes. The cell-bodies are flattened from before backward; the lamellar processes pass between the lamellæ and bundles of connective tissue, branch and anastomose with the processes of neighboring cells (see Plate 4, Fig. 4). The *corneal endothelium* consists of very regular, flat polygonal connective-tissue cells, which do not simply cover the posterior surface of the cornea, but line the entire anterior chamber.

The larger posterior portion of the external tunic of the eye, the *sclera*, shows essentially the same structure as the substantia propria of the cornea, but there is a manifold intertwining of the connective-tissue bundles. On account of this the sclera is opaque and white. It also contains fine elastic fibers which enter into the strands of connective tissue, especially in the posterior portion of the sclera. The cells of the sclera are less regularly arranged and fewer in number than those of the cornea. The stratum proprium of the cornea changes abruptly into the sclera at the sclero-corneal junction. The sclera proper contains *few blood-vessels*, while the cornea contains none. It is the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only structure consisting of fibrous tissue which contains no blood-vessels. In the region of the transition of the cornea into the sclera and near the anterior chamber, a circular vein is found running parallel to the edge of the cornea, the *venous sinus of the sclera* or the canal of Schlemm.

Lymph-vessels are also lacking in the external tunic of the eye, as also in the entire bulbus. On the other hand, very distinct pericellular lymph-spaces are found especially in the cornea, which are connected with each other by spaces corresponding to the processes of the cells.

The sclera contains few *nerves*. These are sensory and terminate in endings resembling tendon corpuscles. The cornea is very rich in nerves. These are also sensory, the branches of which form plexuses in the substantia propria; one situated near the anterior elastic membrane is especially dense and is known as the subepithelial plexus. The terminal branches of this plexus penetrate the corneal epithelium, between the cells of which they terminate (see Fig. 38).

The Tunica Media Bulbi (Uvea).

Between the sclera and the tunica media or choroid of the eye, loose pigmented connective tissue is found, known as the *lamina suprachorioidea* or *lamina fusca*. It contains the larger nerves and blood-vessels for the choroid.

The middle tunic of the eye, *uvea*, is unusually vascular and contains in general all the essential blood-vessels of the eye. In it are recognized three functionally and structurally distinct regions—the *choroid proper*, the *ciliary body*, and the *iris*.

The *choroid* consists of the following layers, enumerated from without inward: (1) The *lamina vasculosa* or *lamina propria*, the principal layer which contains the larger vessels, both arteries and veins, between which there is found a fibrous connective tissue, containing pigment cells; the inner portion of this layer, for a thickness of

PLATE 75.—THE EYE.

FIG. 1.—**Portion of a Transverse Section of the Human Cornea.** × 90.

The preparation was taken from a man who had been executed.

The figure shows the lamination of the cornea.

Technic: Chromic acid solution, 2 per cent. Hematoxylin-eosin.

Reference letters: *en*, Endothelium; *ep*, epithelium; *lea*, anterior elastic or Bowman's membrane; *lep*, posterior elastic or Descemet's membrane; *sp*, stratum proprium.

FIG. 2.—**Portion of a Transverse Section of the Three Coats of the Eye of Man.** × 80.

The preparation was taken from a man who had been executed.

The figure gives a general picture of the structure of the three tunics of the eye.

Technic: Zenker's solution. Hematoxylin-eosin.

Reference letters: *Ch*, Choroid; *chc*, chorio-capillaris; *ES*, episcleral tissue; *R*, retina; *Sk*, sclera.

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about 10 μ, consists mainly of elastic tissue, is free from pigment, and is known as the boundary zone; (2) a thin layer, free from pigment and consisting mainly of large capillary vessels, which serve for the nutrition of the outer layers of the retina; this is known as the *chorio-capillary layer* or *membrane;* (3) a very thin, homogeneous membrane, about 2 μ in thickness, the *membrane of Bruch.*

In the anterior half of the bulb the tunica media forms two special structures, the *ciliary body* and the *iris.* The former consists of two parts: the *ciliary muscle,* which lies close to the adjacent sclera and is the *muscle of accommodation,* and the *processus ciliares,* seventy to eighty meridionally arranged, fold-like elevations, which project toward the vitreous body. In the posterior portion they are low and become gradually higher anteriorly toward the edge of the lens. They are very rich in blood-vessels and serve for the regulation of intra-ocular pressure. The *ciliary muscle* consists of a mass of non-striated muscle formed of outer meridional and inner radiating and circular bundles, passing over into each other without any sharp line of demarcation. The meridional fibers are the longest (*tensor chorioideæ*); they originate from the inner surface of the sclera in the region of the canal of

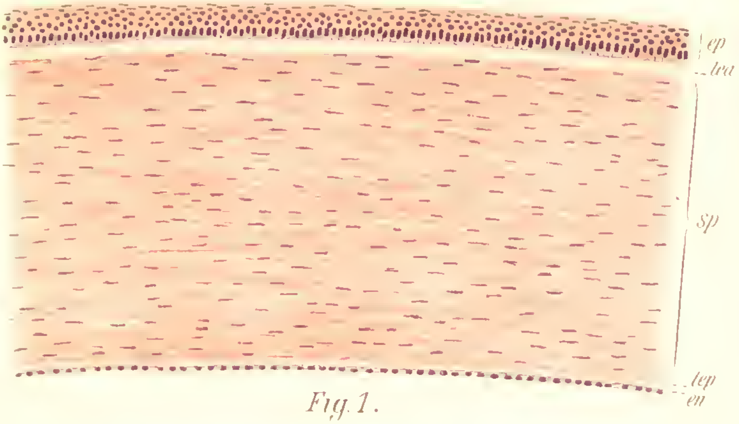

Fig.1.

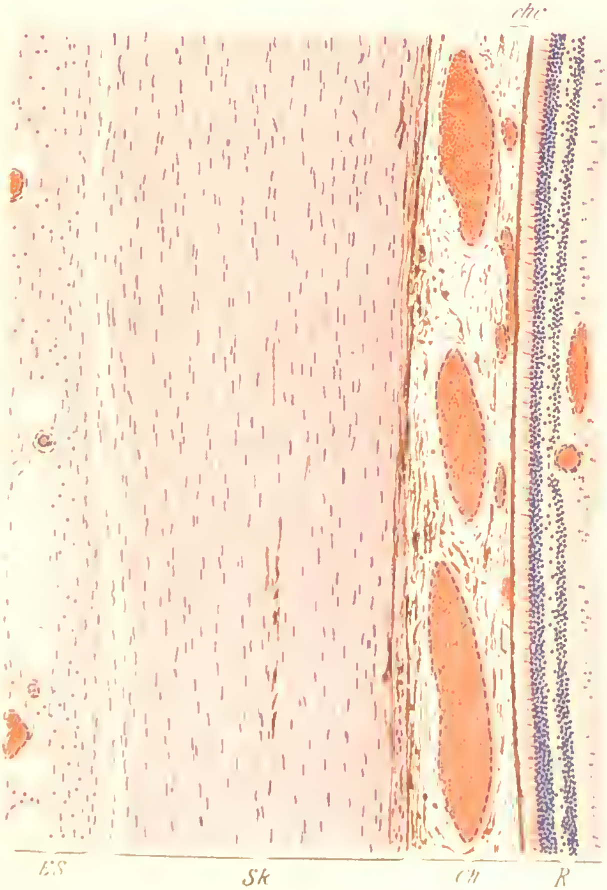

Fig.2.

Schlemm and extend backward over the origin of the ciliary processes.

The *iris* is a thin membrane, in the center of which there is found a circular opening, the pupil. It begins at the anterior edge of the ciliary body and extends to the edge of the pupil, where it ends, generally slightly thickened. We distinguish in the iris four layers: (1) The endothelium of the anterior chamber, which covers the surface of the iris bordering on the anterior chamber; (2) the stratum proprium iridis; (3) the posterior elastic limiting membrane or the membrane of Bruch; (4) the pigment layer of the iris; the latter, however, is the continuation of the tunica interna.

The *endothelium* on the anterior surface of the iris is similar to that on the posterior surface of the cornea. The *stratum proprium* of the iris is divided into two parts which pass over into each other without any sharp line of demarcation—the anterior *reticular* membrane composed of more densely woven connective tissue and the posterior *vascular* and *muscular layer*. The latter consists of non-striated muscle and numerous blood-vessels and connective tissue whose cells contain much pigment in dark eyes and a relatively small amount in blond eyes. The muscle of the iris consists of the *sphincter pupillæ* surrounding circularly the edge of the pupil, and the *dilatator pupillæ* consisting of radiating bundles, lying close to the posterior basal membrane. The two muscles are connected in the region of the pupillary margin. The *lamina basilaris* corresponds in appearance and structure to the similar lamella of the choroid. For the pigment layer of the iris, see under the retina.

The vessels of the *choroid* are essentially the *short posterior ciliary arteries*, while the *long posterior ciliary* and the *anterior ciliary arteries* provide for the nourishment of the ciliary body and the iris. While the choroid vessels in the lamina chorio-capillaris form a very narrow-meshed capillary network, the vessels of the anterior part of the

PLATE 76.—THE EYE.

FIG. 1.—**Portion of a Horizontal Section of the Human Bulb of the Eye; Region of the Ciliary Body.** × 15.

The preparation was taken from a man who had been executed.

The figure shows the transverse section of the entire iris, of the ciliary body with the ciliary processes partly in surface view, the place of junction of cornea and sclera, the conjunctiva bulbi, a portion of the lens, and the fibers of the zonula.

Technic: Chromic acid, 2 per cent. Hematoxylin-eosin.

Reference letters: *C*, Cornea; *Ch*, choroid; *Co*, conjunctiva bulbi; *coa*, anterior chamber of eye; *cop*, posterior chamber of eye; *cl*, capsule of lens; *Ir*, iris; *L*, lens; *le*, lens epithelium; *Mc*, ciliary muscle; *Pc*, ciliary processes; *Pcr*, pars ciliaris retinae; *Sc*, sclera; *Spp*, sphincter muscle of pupil; *stp*, pigment layer of iris; *svsc*, sinus venosus or canal of Schlemm; *Z*, zonula ciliaris.

FIG. 2.—**Portion of a Horizontal Section of the Lens in the Region of the Equator.** × 220.

The preparation was taken from a man who had been executed.

The figure shows the epithelial fiber limits of the lens. The transition of the cubic lens epithelium of the anterior surface into the elongated lens-fibers at the equator of the lens.

Technic as in Fig. 1.

Reference letters: *cl*, Capsule of lens; *ep*, lens epithelium; *lf*, lens-fibers.

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uvea form at the base of the iris a vascular ring, the *circulus iridis major*, from which the vessels of the ciliary body and the radiating vessels (capillary vessels) of the iris proceed, which surround the pupillary margin circularly, forming the circulus iridis minor. The veins of the uvea are, aside from the sinus venosus or canal of Schlemm, four large veins, lying in the region of the equator of the bulbus, the *venæ vorticosæ.* The *nerves* of the choroid are essentially vascular nerves, while those of the iris and ciliary body are muscular nerves from the sympathetic, the sphincter of the pupil and the ciliary muscle receiving their innervation through neuraxes of sympathetic neurones of the ciliary ganglion, the dilator of the pupil through neuraxes of neurones of the superior cervical ganglion. Sensory nerves terminate in free sensory endings in the ciliary body and iris.

Tab. 76.

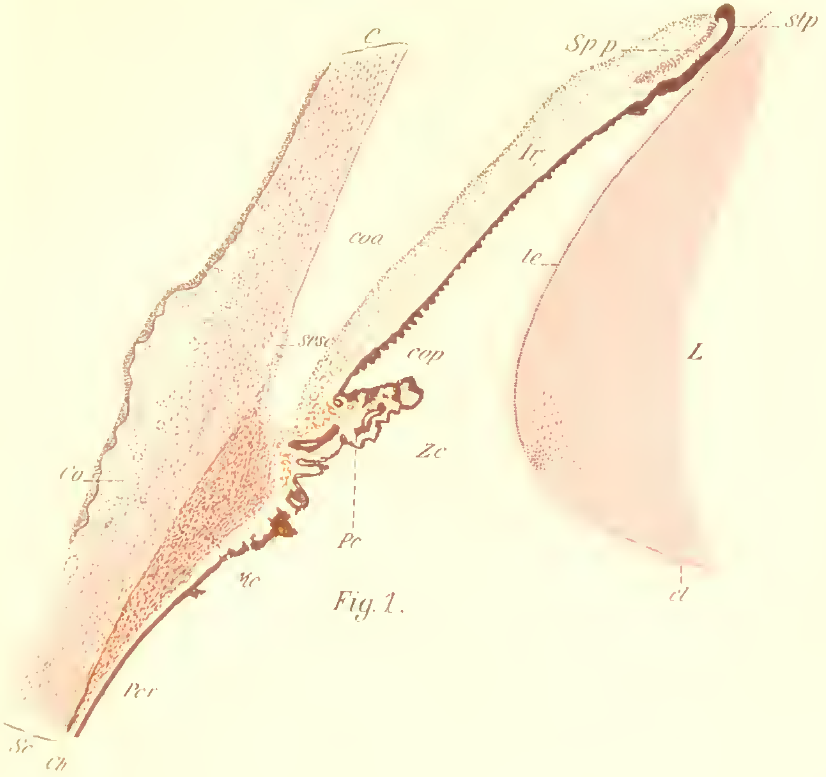

Fig. 1.

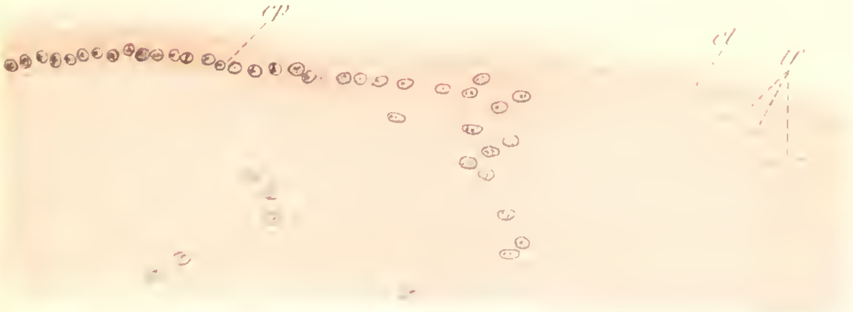

Fig. 2.

Retina or Tunica Interna.

The tunica interna consists of two main layers, the *pigment epithelium* and the true *retina.* They represent the two adjacent layers of the secondary optic vesicle or optic cup.

The *pigment epithelium*, the outer layer of the optic cup, consists of very regular, hexagonal cells of flattened cubic form, which consist of an outer half showing little pigment and containing the nucleus, and an inner, markedly pigmented half adjoining the retina (see Plate 3, Fig. 4).

The *retina* is divided into two main portions, the *pars optica* or retina proper and the *pars cæca.* The latter is divided again into the *pars ciliaris* and *pars iridica retinæ*, two portions which are not sharply separated. The pars optica and the pars cæca are separated by a sharp line, which has generally a slightly wavy course and is macroscopically visible, the *ora serrata.* The finer structure of the retina is complicated and in some parts not fully interpreted, so that the discussion is here limited to the most important points and those which are well understood. The structure of the retina proper (*pars optica retinæ*) is essentially as follows: It consists of three elements differing in structure and function: the *supporting elements*, the *nervous constituents*, and the *neuro-epithelial layer.* The supporting elements are intimately connected with the other two constituents, and, like the elements of these, can be distinguished in their whole extent only after the application of special methods. On observation of the retina by the usual methods of investigation, it appears to be composed of a number of layers, which, reckoning from within outward, are as follows: (1) Membrana limitans interna; (2) layer of optic nerve-fibers; (3) layer of ganglion-cells; (4) inner reticular or plexiform layer; (5) inner granular layer; (6) outer reticular or plexiform layer; (7) outer granular layer; (8) outer limiting membrane; (9) rods and cones. We retain here the old classification of layers, which, in spite of its incompleteness, cannot be dispensed with for the time until a new and satisfactory nomenclature is at hand. Of these layers, the *limiting membranes* belong to the supporting elements, the layer of *optic nerve-fibers*, the layer of *ganglion-cells*, the *inner granular* layer, and the *inner* and part of the *outer plexiform* layers are to be counted among the nervous constituents, while the *outer granular* layer, with a portion of the *outer plexiform* layer and the layer of rods and cones, represent the neuro-epithelium.

The supporting framework of the retina is formed of the *supporting fibers of Müller*. These extend through the entire thickness of the retina, beginning at the inner surface of the retina with cone-shaped enlargements known as *foot-plates*, which by their fusion form the internal limiting membrane. They have nuclei which are situated in the inner granular layer. It has been shown by means of special methods that they give off lateral branches in both plexiform layers, and in the granular layers show impressions from the pressure of the elements of these layers. The Müller's fibers form the external limiting membrane, a membranous structure with openings for the rods and cones and fine processes projecting between the rods and cones called *fiber baskets*. Besides the Müller's fibers, glia cells and fibers are found in the retina, but only in the layer of optic nerve-fibers.

The *layer of nerve-fibers* is formed of the non-medullated fibers of the optic nerve. They constitute in the main the neuraxes of the nerve-cells of the *ganglion-cell layer*, which contains large multipolar ganglion-cells. The dendrites of these ganglion-cells spread out in the inner plexiform or reticular layer. The *inner plexiform layer* contains the terminal branchings of the dendrites of the neurones of the ganglion-cell layer, as well as the neuraxes of the neurones of the inner granular layer and dendrites and neuraxes of other ganglion-cells.

The *inner granular layer*, or, as it may better be known, the inner ganglion-cell layer, is composed of several distinct kinds of elements: (1) The nuclei of the Müller's fibers; (2) small *bipolar ganglion-cells*, the nuclei of which represent the main mass of the "granules" of this layer, the neuraxes of which penetrate into the inner plexiform layer and there branch, while the dendritic processes show the same relation to the outer plexiform layer; they are said to penetrate even to the cells of the outer granular layer; (3) two groups of cells, concerning the relation of which the views are still contradictory. Certain of these cells bear the name of *spongioblasts* or *amakrine cells*, also known as *parareticular cells* on account of their situation at the borders of the inner plexiform or reticular layer; they are ganglion-cells of the second type of Golgi's classification, with rich branching of their neuraxes in the inner plexiform layer. Another type of cells found in the inner granular layer is represented by the *horizontal cells;* they lie mostly at the borders of the outer plexiform layer and send out a neuraxis which runs horizontally. Together with the amakrine cells they are said to form a reflex arc in the retina. The *outer plexiform layer* consists again of a dense network of cell processes. The *outer granular* or *nuclear layer* contains two kinds of cells: The main part is formed by the *rod visual cells;* the second form, the *cone visual cells*, lie with their nuclei generally close to the outer limiting membrane. To these cells belong also the *rods* and *cones*, which are probably to be regarded as cuticular formations of the cells. The *rod visual cell* consists of the *rod*, lying outside of the external limiting membrane, and the *rod fiber*, lying internal to that membrane. The rod fibers are long, slender cells, which show an enlargement, the *rod granule*, at the place of the nucleus. The inner central end of the fiber is thickened at its ending in the plexiform layer. The *rod* consists of a somewhat broader, rod-like, granular inner segment and an exactly cylindric, somewhat narrower homogeneous outer segment. The outer segment, which is doubly refractive, may be separated by certain reagents or by certain methods of staining into transverse discs. The inner end of the inner segment shows a delicate superficial striation.

Like the rod visual cells, the *cone visual cells* consist of cones and cone fibers. In the *cone fibers* the nucleus lies close to the external limiting membrane; the real fibers, therefore, lie internal to the nucleus and extend through the outer granular layer to the outer plexiform layer, where each ends in a cone-shaped enlargement, the *cone foot*. The *cones*, like the rods, have an inner and an outer segment. The former are thick flask-shaped; the latter are short, much shorter than the outer segments of the rods, and have the form of a narrow cone. The structure of the cones is otherwise essentially the same as that of the rods. Not all cones have the same form; at the periphery of the retina, near the ora serrata, are very short broad cones, while the region of the macula lutea has long narrow cones, and the cones of the region of the fovea centralis are so long and narrow that they assume almost the form of rods and are known as *foveal cones*. The number of rods is greater than that of the cones. Generally four to five rods occur to each cone. Only in the middle of the macula lutea and partly also in the neighborhood of the ora serrata is the relative proportion altered (see page 227).

The *elements of the retina*, aside from the amakrine and horizontal cells, are so connected that the light impulse is carried through the rod and cone fibers into the outer plexiform layer. Here these are in contact with the peripheral dendrites of the bipolar cells of the inner granules. The bipolar cells of the inner granules again enter into contact by means of their neuraxes with the dendrites of the nerve-cells of the ganglion-cell layer, the neuraxes of which form the optic fibers. Three portions of the retina are especially distinguished on account of their structure: the *ora serrata*, the *fovea centralis*, and the *place of entrance of the optic nerve*.

Before reaching the *ora serrata* the retina becomes essentially thinner. The optic fiber layer is entirely lacking; only a few scattered ganglion-cells are found. Finally the plexiform layers and the inner and outer granular layers become confluent and form the cubic epithelium of the pars ciliaris retinæ. Rods and especially broad, short cones extend to near the edge of the ora serrata. Large

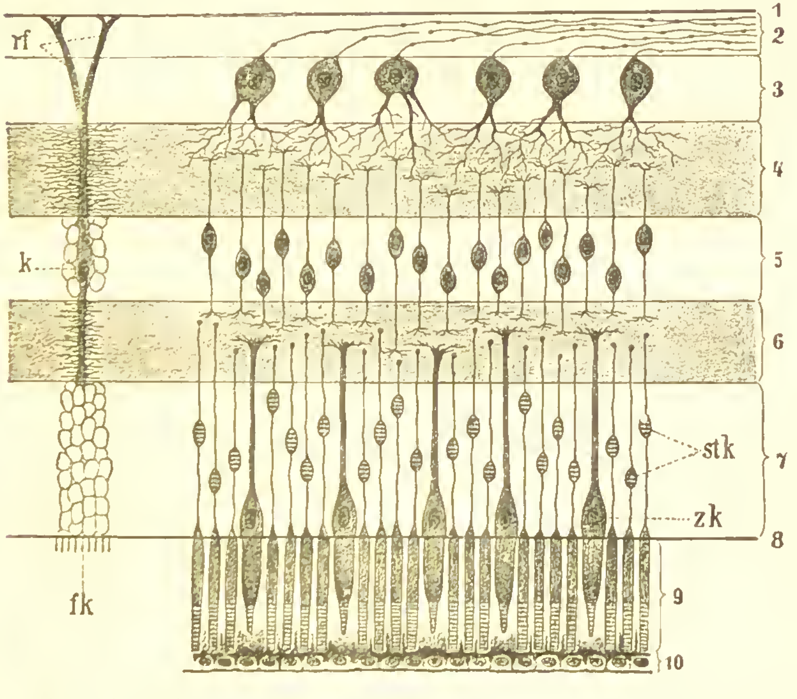

Fig. 61.—Diagrammatic representation of the elements of the retina and of its nervous relations (without consideration of the amakrine and horizontal cells); to the left the supporting elements, to the right the nervous elements and neuro-epithelium. *fk*, Fiber baskets of Müller's fibers; *k*, nucleus of Müller's fiber; *rf*, fiber cone of Müller's fibers; *stk*, rod nucleus; *zk*, cone nucleus; *1*, internal limiting membrane; *2*, layer of optic fibers; *3*, ganglion-cell layer; *4*, inner plexiform layer; *5*, inner granular layer; *6*, outer plexiform layer; *7*, outer granular layer; *8*, outer limiting membrane; *9*, rods and cones; *10*, pigment epithelium.

PLATE 77.—EYE.

FIG. 1.—**Portion of a Cross-section of the Retina of Man in the Neighborhood of the Place of Entrance of the Optic Nerve.** × 180.

The preparation was taken from a man who had been executed.

The figure represents the typical lamination of the retina. Nerve-fiber, ganglion-cell, and inner granular layers are relatively well developed.

Technic: Zenker's solution. Hematoxylin-eosin.

Reference letters for Figs. 1–3: *1*, Internal limiting membrane; *2*, layer of optic nerve-fibers; *3*, ganglion-cell layer; *4*, inner plexiform layer; *5*, inner granular layer; *6*, outer plexiform layer; *7*, outer granular layer; *8*, external limiting membrane; *9*, rods and cones; *9**, cones and foveal cones; *10*, pigment epithelium; *bg*, blood-vessels of the retina; *ch*, choroid; *per*, pars ciliaris retinæ; *rf*, Müller's fibers; *v*, vacuole.

FIG. 2.—**Transverse Section through the Fovea Centralis of the Human Retina.** × 125.

The preparation was taken from a man who had been executed.

The figure shows the changes which the retinal layers undergo in the region of the fovea centralis.

Technic: Sublimate. Hematoxylin-eosin.

FIG. 3.—**Meridional Section through the Ora Serrata of Man.** × 100.

The preparation was taken from a man who had been executed.

The figure shows the gradual confluence of all the retinal layers, which often contain vacuoles, into the simple columnar cells of the pars ciliaris retinæ.

Technic: Chromic acid, 2 per cent. Hematoxylin-eosin.

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hollow spaces are often found in varying number in the retina at the ora serrata, thought to be due to edema.

The *fovea centralis* presents a number of peculiarities of lamination, which continue partly into its nearest surroundings, but in the region of the macula lutea pass over into the usual structure of the retina.

The ganglion-cell layer thickens considerably in the region of the fovea centralis and macula lutea, so that its elements form from five to eight layers and the inner granular layer is much broader. Henle's fiber layer, cone and rod fibers, which here form a distinct layer between the outer granular and plexiform layers, is very distinct. In place of the rod and cone visual cells, *cones alone* occur, which, toward the base or fundus of the fovea,

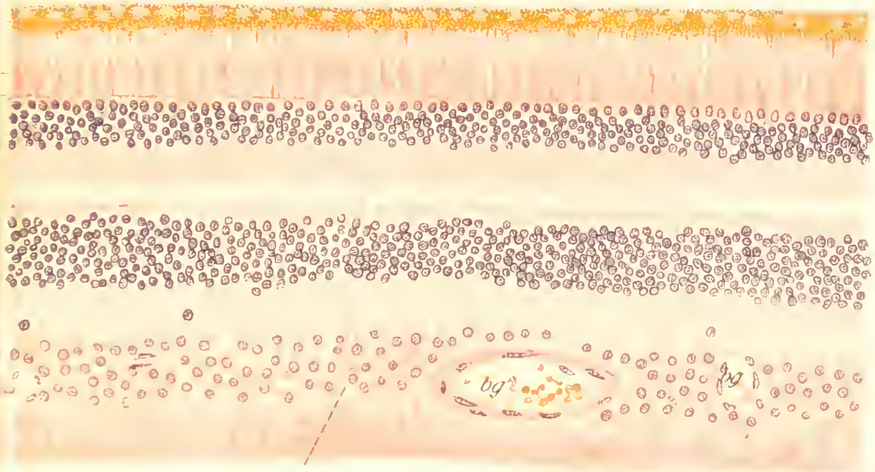

Fig. 1.

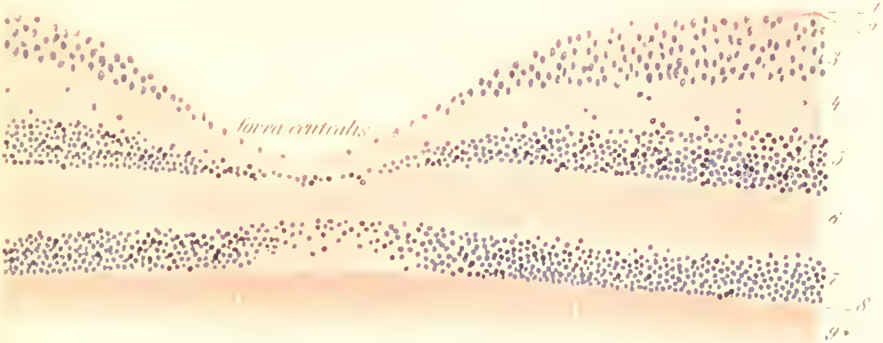

Fig. 2.

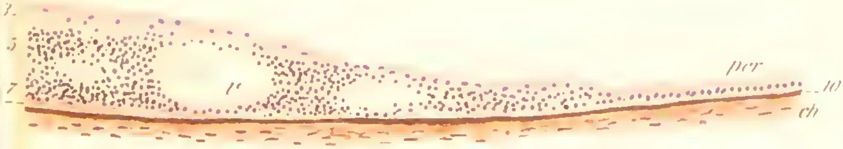

Fig. 3.

increase in length and diminish in caliber (compare page 224). Corresponding to this, the outer granular layer consists only of cone visual cells, the nuclei of which do not all lie in close relation to the external limiting membrane, as in other parts of the retina. The *fundus foveæ* is characterized by the fact that nearly all the layers of the retina are lacking except the foveal cones. All the others, especially the inner layers, are here reduced to a minimum and pushed aside and thus increase the slope of the depression, the outer granular layer being reduced first.

At the point of entrance of the optic nerve, the *optic papilla,* all the retinal layers are lacking except that of the nerve-fibers. The *pars cæca retinæ* presents differences in the regions of the pars iridica and pars ciliaris retinæ, as in the former the pigment epithelial layer and the retinal layer are both pigmented, while in the latter the retinal layer consists of cubic or low columnar unpigmented cells in a single layer.

Only the pars optica retinæ contains *blood-vessels* which rise from the arteria centralis retinæ and open into the vena centralis. These blood-vessels nourish only the inner layer of the retina and lie in the layer of nerve-fibers, rarely in the layer of ganglion-cells. The fovea centralis, as well as the neighborhood of the ora serrata, is non-vascular. As has been stated, the outer layers of the retina are supplied by the dense vascular network in the chorio-capillary layer of the choroid, whose main function this would seem to be.

The Optic Nerve.

The *optic nerve* has three sheaths, which correspond to the *dura mater, arachnoid,* and *pia mater* of the central nervous system. The *fibers* of the optic nerve, like those of the central nervous system, are medullated, but are without the sheath of Schwann. The pia mater sends numerous *septa* into the interior of the nerve and thus forms small bundles of *optic nerve-fibers.* Within the bundles the frame-

PLATE 78.—EYE, LACHRYMAL GLAND.

FIG. 1.—**Longitudinal Section of the Place of Entrance of the Optic Nerve in the Human Eye.** × 18.

The preparation was taken from a man who had been executed.

The figure shows the optic nerve with its sheaths and fiber-bundles, the passage through the lamina cribrosa scleræ and the spreading out of the fibers in the upper layer of the retina. In the axis the vena centralis is met. Surrounding the papilla nervi optici we see the cross-section of the coats of the eye.

Technic: Sublimate. Hematoxylin-eosin.

Reference letters: *Ch*, Choroid; *d*, dural sheath of optic nerve; *epn*, physiologic excavation of the papilla of the optic nerve; *fno*, bundles of the optic nerve; *lc*, lamina cribrosa of the sclera; *no*, optic nerve; *p*, pia-arachnoidal sheath of the optic nerve; *R*, retina; *Sc*, sclera; *vc*, vena centralis.

FIG. 2.—**Portion of a Transverse Section of the Human Lachrymal Gland.** × 120.

The preparation was taken from a man who had been executed.

The figure shows the loose arrangement of the lobules of the lachrymal gland, which are separated by connective tissue. In the gland tissue secreting tubules and smaller excretory ducts are visible.

Technic: Sublimate. Hematoxylin-eosin.

Reference letters: *bdg*, Connective tissue rich in lymph-cells; ds_1, median excretory duct; ds_2, small excretory duct; *F*, adipose tissue; *s*, secretion; *ts*, tubule with branchings and dilations.

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work is formed, not of endoneurium, as in the peripheral nerves, but by *neuroglia tissue.* As in the central nervous system, the optic nerve has a peripheral *neurogliar mantle.* In the interior of the optic nerve are found the central vein and artery of the retina.

The fibers of the optic nerve become non-medullated in passing through the sclera. At the entrance of the optic nerve the sclera is penetrated by small openings, this area being known as the *area cribrosa ;* the choroid is here entirely lacking. The non-medullated fibers of the optic nerve spread out on the retina, forming a flattened elevation with a slight hollow in the center ; these are known as the *optic papilla,* with the *physiologic excavation* in the center.

The Vitreous Body and the Zonula Ciliaris.

The *vitreous body* is rich in fluid and contains some few connective-tissue fibers and leukocytes ; connective-tissue

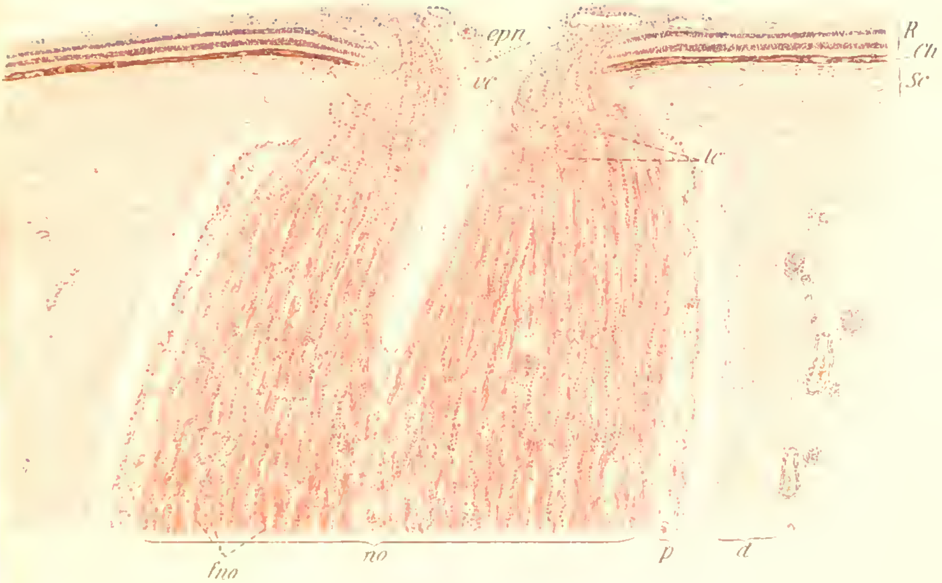

Fig. 1.

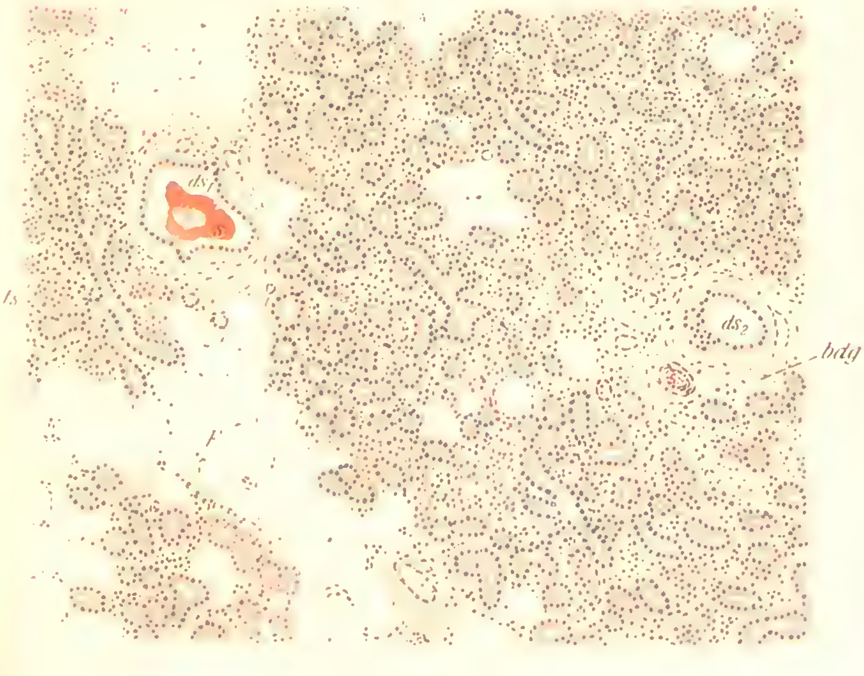

Fig. 2.

cells are said not to occur in the vitreous body. The *zonula ciliaris* consists of *structureless fibers,* which arise from the epithelial cells of the pars ciliaris retinæ in the valleys between the ciliary processes, and, covering the ciliary processes, pass toward the lens. The zonula fibers form several not sharply differentiated layers and cross each other many times before reaching their attachment in the region of the lens.

The Lens.

The *lens* is an epithelial structure which takes its origin from the ectoderm. It consists of a *homogeneous capsule,* the *capsule of the lens,* which is thinner behind than in front, surrounds the entire lens, and bears on its inner side, in the region of the anterior surface of the lens, a simple *cubic epithelium,* the lens epithelium. At the equator of the lens this changes gradually into fiber-like cells which extend from the anterior surface of the posterior capsule to the lens epithelium. The main mass of the lens is formed of these *lens-fibers* (see Plate 76, Fig. 2). The lens-fibers are long, six-sided, often flattened prisms, which generally have an oval nucleus; only the so-called central fibers and transition fibers of the human lens are non-nucleated. The main portion of the lens-fibers are arranged in radial lamellæ. The number of these lamellæ amounts to about 2000. Neither the vitreous body nor the lens contains blood-vessels and nerves.

The Auxiliary Apparatus of the Eyeball.

The Eyelid.—The *eyelids* are folds of the skin, which on the anterior surface present the usual structure of the skin, while the posterior surface is covered by the conjunctival mucous membrane. From before backward we distinguish in the eyelid the following layers: (1) The skin with the lanugo hairs, sebaceous and sudoriferous glands; (2) subcutaneous tissue; (3) the M. orbicularis palpebrarum; (4) loose connective tissue with the main vessels of

PLATE 79.—EYELID.

Vertical Section of the Upper Eyelid of Man. × 14.

The preparation was taken from a man who had been executed.

The figure gives a general view of the structure of the eyelid, showing its different layers. Two cilia are met in the section, one of which is in the process of falling out. A small accessory lachrymal gland is seen on the conjunctival surface.

Technic: Müller's fluid. Hematoxylin-eosin.

Reference letters: *at*, Arterial arcus tarseus; *C*, cilia; *dgl*, excretory duct of tarsal gland; *glc*, ciliary gland (Moll); *glla*, accessory lachrymal gland; *glt*, Meibomian gland; *McR*, ciliary muscle of Riolani; *Mop*, M. orbicularis palpebrarum; *Mt*, non-striated muscle-fibers of the tarsal muscle and tendon of the levator palpebræ superioris; *nlc*, lymph-nodes of the conjunctiva palpebræ; *T*, tarsus.

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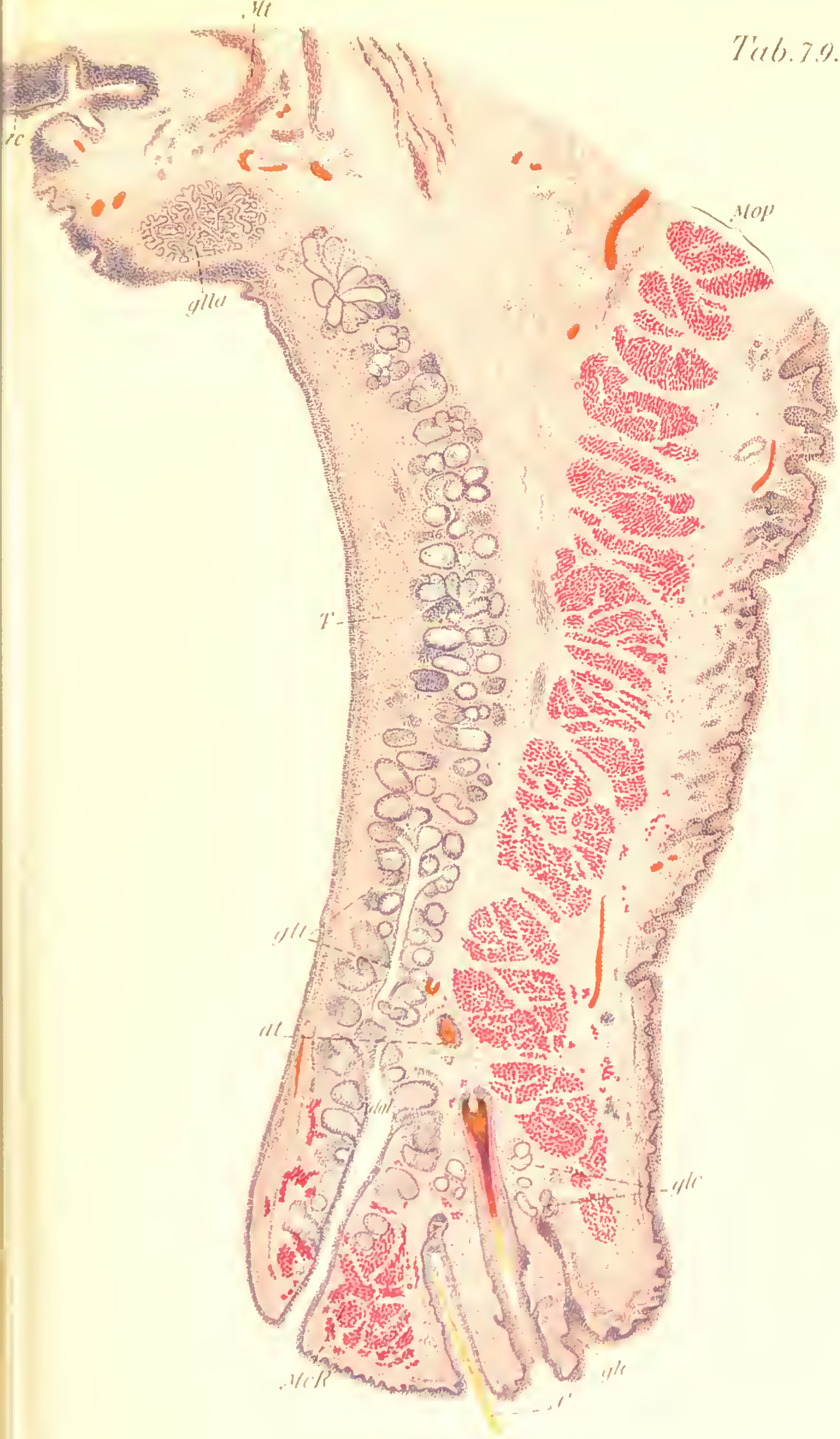
the lid; (5) the tarsus with the tarsal glands; (6) the conjunctiva palpebrarum.

The *skin of the lid* presents no peculiarities. Between the outer and inner edges of the lids it passes gradually over into the conjunctiva. Here one or two layers of relatively thick hairs are found, the *cilia*, which are characterized by the fact that they are regularly and quite frequently shed, and as a consequence club-hairs are often found. In the region of the cilia are found the *ciliary glands* or the *glands of Moll*, modified sudoriferous glands, which differ from the ordinary sweat-glands in that they branch and possess relatively large oval or spheric alveoli. A portion of the *palpebral muscle* pushes between the cilia and the inner edge of the lid and is designated as the *M. tarsalis*, or the ciliary muscle of Riolani. This surrounds the opening of the Meibomian glands to a varying extent with bundles of transversely striated muscle. The main mass of the *palpebral muscle* is separated from the skin of the lids by loose subcutaneous connective tissue. Between the muscle and the tarsus is loose connective tissue often containing fat, which surrounds the larger *blood-vessels* and *nerve trunks* of the lid. In the neighborhood of the roots of the cilia the arterial *arcus tarseus* is found.

The *tarsus* or *lid cartilage* is composed of dense formed


Mt
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connective tissue. Its entire length is occupied by the *Meibomian glands*, which correspond in their finer structure to the sebaceous glands of the hair-bulbs. They have a long median duct, which is surrounded by the gland alveoli. The large excretory duct, which has no alveoli, is lined by stratified pavement epithelium and opens close to the inner margin of the lid. The posterior surface of the tarsus is covered by the *conjunctiva palpebrarum*, which is attached to the tarsus. Its mucous membrane is rich in lymph-cells, which form *solitary follicles* in the region of the fornix conjunctivæ. The mucous membrane of the conjunctiva palpebrarum has no papillæ; the epithelium is stratified columnar, papillæ occurring only in the region of the fornix conjunctivæ. At the upper end of the tarsus is the insertion of the tendon of the *M. levator palpebræ* mingled with non-striated muscle-fibers. Small *accessory lachrymal glands*, of the same structure as the main glands, are often situated near the upper end of the tarsus close under the conjunctiva. The *conjunctiva bulbi* is covered by stratified pavement epithelium, under which we find a papillated mucosa. The nerves of the conjunctiva end partly in free endings and partly in Krause's spheric end-bulbs.

The Lachrymal Glands.—The *lachrymal gland* is a compound tubular gland, which is not sharply separated from the surrounding tissue and is embedded in fat tissue. Adipose tissue in variable amount is also found between the lobules of the gland. (See Plate 78, Fig. 2.) The cells of the secreting tubules, which are distinctly branched, are cubic to columnar, and the lumen of the canals is generally quite narrow; when the tubules are empty, the cells are lower; but when they are filled with the secretion, their surface on the side of the lumen appears clear. In addition to these cells, much flatter cells occur, which are easily distinguished from the columnar cells. *Intermediary ducts* with low epithelium form the transition to the *excretory ducts*, the smaller of which are lined by cubic

PLATE 80.—ORGAN OF HEARING.

FIG. 1.—**Portion of a Transverse Section of the External Auditory Canal of Man.** × 15.

The preparation was taken from a man who had been executed.

The figure gives a general view of the cartilaginous external auditory canal.

Technic: Müller's fluid. Hematoxylin-eosin.

Reference letters: *glc*, Ceruminous glands; *glsc*, sebaceous glands; *kn*, cartilage.

FIG. 2.—**Portion of a Cross-section of a Cochlea of a New-born Child.** × 50.

The preparation was taken from a still-born child.

The figure shows the cross-section of a duct of the osseous cochlea and gives a general view of the ductus cochlearis.

Technic: Hermann's solution. Hematoxylin-eosin.

Reference letters: *bg*, Blood-vessels; *dc*, ductus cochlearis; *gsp*, spiral ganglion; *Kn*, bone; *lsp*, limbus spiralis; *lspm*, lamina spiralis membranacea; *lspo*, lamina spiralis ossea; *mv*, membrana vestibularis or Reissner's membrane; *n*, nervus acusticus; *sct*, scala tympani; *vp*, vas prominens; *scv*, scala vestibuli.

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epithelium, the larger by columnar epithelium showing two layers of cells. Sympathetic nerve-fibers have been traced to the cells of the secreting tubules.

THE ORGAN OF HEARING.

The organ of hearing consists of the external ear, the middle ear, and the inner ear. The *external ear* is composed of the *pinna* of the ear and the *external auditory canal.* The tympanic membrane separates the external ear from the middle ear. The *external ear* consists of a cartilaginous framework of *elastic cartilage,* which is covered by skin.

The *external auditory canal* has a framework consisting partly of elastic cartilage and partly of bone, to which is intimately attached a thick mucous membrane. The latter is really a continuation of the skin, and, like this, presents stratified pavement epithelium with small hair follicles and relatively large sebaceous glands and especially large *sudoriferous glands* known as *ceruminous glands.* These

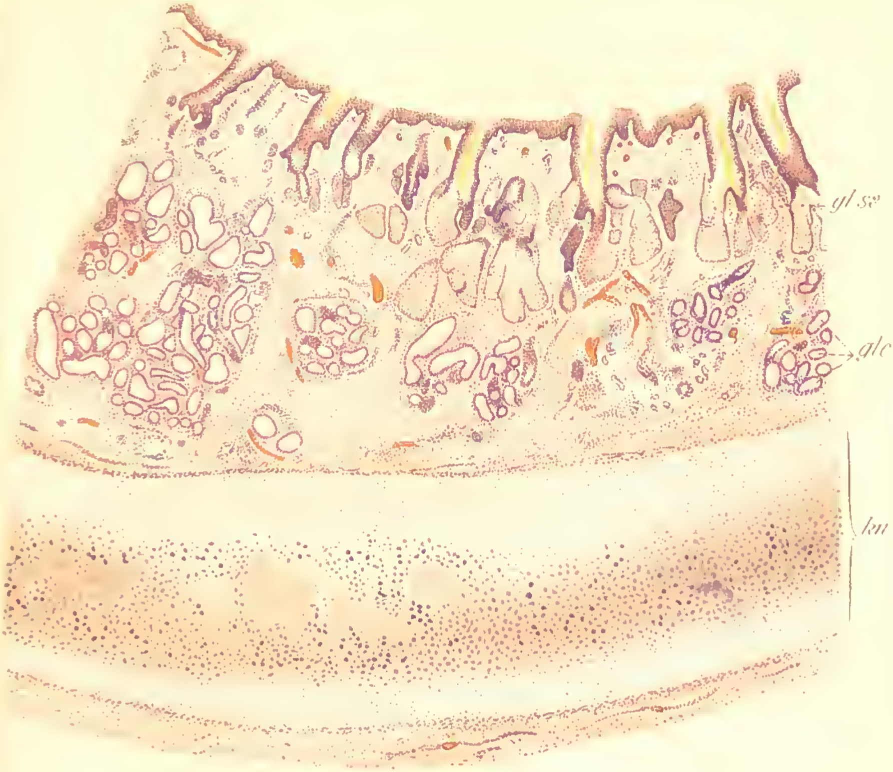


Fig. 1.

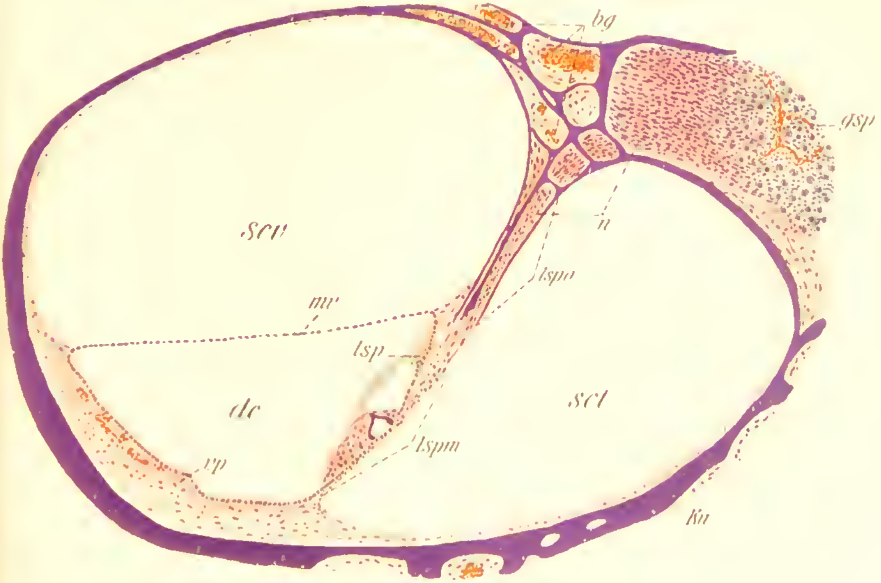


Fig. 2.

have very large coils composed of branched tubules with large lumen, high epithelium, and distinct non-striated muscle-fibers, like the axillary glands (see page 211). The excretory ducts are short in comparison with those of other sudoriferous glands. The glandular epithelium contains pigment granules and often fat granules.

The *middle ear*, the tympanic cavity, has a thin mucous membrane, often with ciliated flattened epithelium, which changes in the *Eustachian tube* to a stratified ciliated epithelium. Glands are absent. The *tympanic membrane* is a connective-tissue membrane, which is covered on the tympanal side by the mucous membrane of the middle ear, on the outer side by the mucous membrane of the external auditory canal.

The Inner Ear (Labyrinth).

Sacculus, utriculus, and **semicircular canals** present in general the same structure.

The *membranous ducts* are composed of a flattened epithelium, a basal membrane, and a connective-tissue sheath. Loose connective-tissue trabeculæ unite the membranous ducts to the bony wall. Between the connective-tissue trabeculæ is found the perilymph. At the *maculæ* and *cristæ acusticæ* the epithelium is thickened. In those places where the endings of the vestibular nerve are distributed, a typical sensory epithelium is found, which presents two kinds of cells: (1) The hair-cells, columnar cells situated at the border, with ciliated margin; the cilia are known as auditory hairs; (2) the long fiber-cells occupying the entire thickness of the epithelium, narrow and broadened only at the lower basal ends. The fiber-cells are probably supporting cells. On the auditory hairs are crystals of calcium carbonate called *otoliths*. The fibers of the N. vestibuli become non-medullated at the basal surface of the epithelium, pass between the hair-cells, and end on their lateral surfaces, at the same time branching at their bases.

Fig. 62.—Transverse section of the osseous and membranous semicircular canal of a new-born child. × 55. The figure shows in the upper portion, excentrically placed, the cross-section of the membranous semicircular canal, which is connected with the osseous wall by some few connective-tissue trabeculæ. *bdg*, Connective-tissue trabeculæ; *bg*, blood-vessels; *ep*, epithelium of the membranous duct; *kn*, osseous wall; *knr*, cartilaginous remains; *p*, periosteum.

Fig. 63.—Transverse section of the macula acustica of the cat. × 120. The figure presents the thickening of the epithelium in the region of the macula acustica and the entrance of the nerve, the fibers of which are medullated until they reach the basal membrane. *ep*, Columnar epithelium, forming the transition of the flattened epithelium into the sensory epithelium; *n*, branch of nervus vestibuli; *nf*, some medullated nerve-fibers approaching the epithelium.

The Cochlea.

The *cochlea* presents a far more complicated structure than the semicircular canals. The *membranous cochlea*, the *ductus cochlearis*, corresponds to the membranous semicircular canals; the spaces of the scala tympani and scala vestibuli represent the perilymphatic space.

The ductus cochlearis is a spirally twisted canal, triangular in cross-section. The thin *membrana vestibularis* or Reissner's membrane forms its boundary on the side of the scala vestibuli; its base consists of the *lamina spiralis membranacea* and partly also of the *lamina spiralis ossea*, which form the boundary on the side of the scala tympani; the lateral wall lies against the periosteum of the outer wall of the bony cochlea. On the inner surface of Reissner's membrane the *epithelium* of the cochlear duct is flat; on the lateral wall, cubic. The epithelium on the membrana spiralis represents a highly differentiated and specialized *neuro-epithelium*, the so-called *organ of Corti*. Reissner's membrane is inserted on the surface of the lamina spiralis ossea close to its free end, so that a part of the osseous spiral lamina forms the tympanal boundary of the cochlear duct. At the place of attachment of Reissner's membrane, the periosteum of the osseous spiral membrane is thickened to form the limbus spiralis; this thickening projects freely into the cochlear duct and is known as the labium vestibulare.

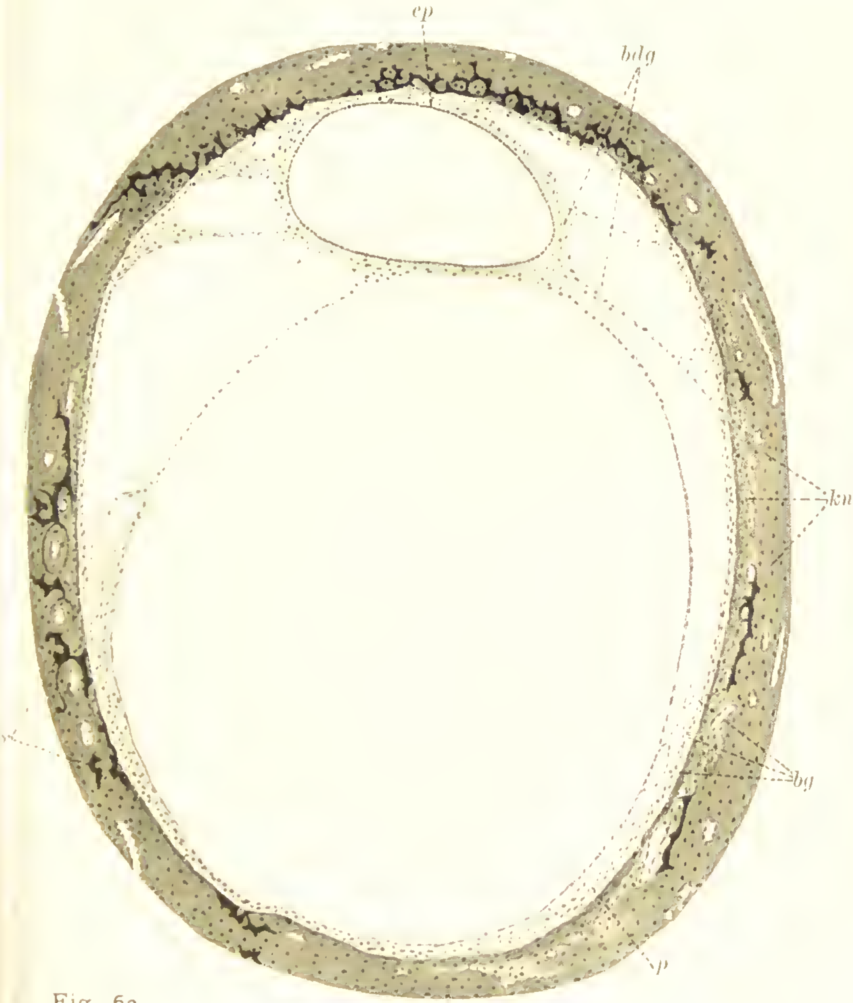


Fig. 62.

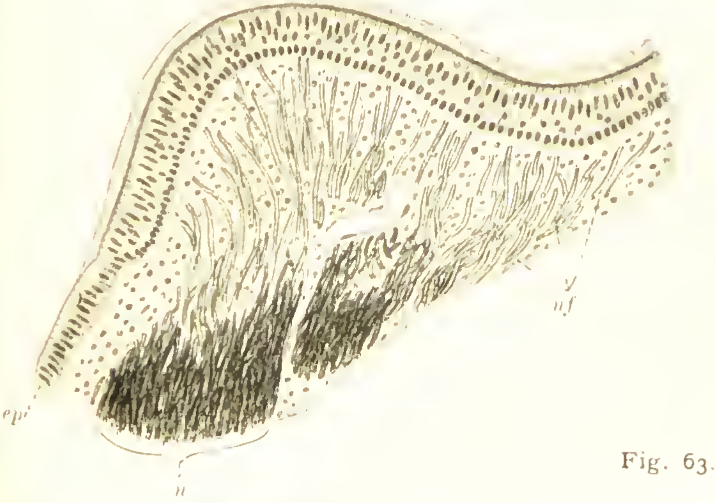


Fig. 63.

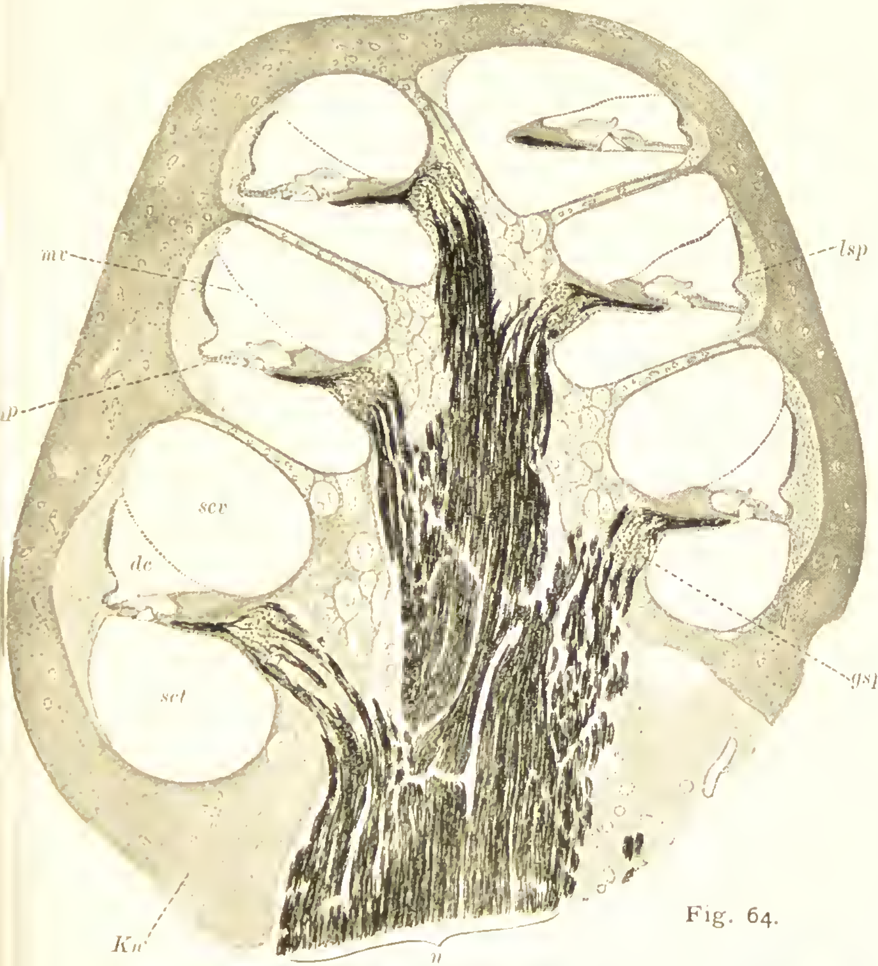
A similar periosteal thickening is found on the inner surface of the outer cochlear wall, where the membranous spiral lamina is attached; this is known as the ligamentum spirale. That portion of the ligamentum spirale which forms the outer wall of the cochlear duct is rich in blood-vessels and is designated as the stria vascularis; in it one very prominent vessel is found projecting into the cochlear duct and the elevation is termed the vas prominens. The membranous spiral lamina is a membrane composed of fine connective-tissue fibers with oblong flattened nuclei. It is attached to the free end of the osseous spiral lamina at the labium tympanicum. The crypt of the cochlear duct which lies between the labium vestibulare and labium tympanicum is called the sulcus spiralis. On the under surface of the membranous spiral lamina is found a connective-tissue layer from the periosteum of the scala tympani, the fibers and nuclei of which are vertical to those of the membranous spiral lamina, the so-called tympanal parietal layer. This generally contains a blood-vessel, the vas spirale. The cubic to columnar epithelium of the *limbus spiralis* changes at the labium vestibulare into peculiar flat processes called *auditory teeth*. The epithelial cells of this region form a thin cuticular structure of fibrous appearance, which is often slightly curved at the end, extending from the labium vestibulare to the cells of the organ of Corti. It is known as the *membrana tectoria*.

The *organ of Corti*, which is formed from the epithelium of the base of the cochlear duct, is situated on the membranous spiral lamina. It is composed for the most part of three special kinds of cells: the *pillar cells*, the *hair-cells*, and the *cells of Deiters*. The *pillar cells* lie in two spiral rows, an outer and an inner. They are to be regarded as supporting cells of the organ of Corti. They consist for the most part of a cornified substance and stand with the base on the basilar membrane, while the broadened heads are in contact with the pillars opposite;

Fig. 64.—Longitudinal section of the cochlea of the cat. × 25. The figure gives a general view of the cochlea. The section was cut through the modiolus; in the modiolus of the cochlea we see the cochlear branch of the nervus acusticus and its branchings in the lamina spiralis. The cochlear duct is met six times in the section. *dc*, Cochlear duct; *gsp*, spiral ganglion; *Kn*, osseous cochlear wall; *lsp*, ligamentum spirale; *msp*, membrana spiralis; *mv*, membrana vestibularis; *N*, nervus cochlearis; *sct*, scala tympani; *scv*, scala vestibuli.

Fig. 65.—A portion of the section from Fig. 64 under higher magnification. × 180. The figure shows the membranous spiral lamina, with the organ of Corti upon it. *ah*, Outer hair-cells; *apf*, outer pillars; *Clz*, cells of Claudius; *Dz*, cells of Deiters; *essp*, epithelium of the sulcus spiralis; *Hz*, cells of Hensen; *ih*, inner hair-cells; *ipf*, inner pillar cells; *lv*, labium vestibulare; *mb*, membrana basilaris; *mt*, membrana tectoria; *n*, branch of the cochlear nerve; *nf*, non-medullated nerve-fiber in the pillar tunnel; *Nr*, space of Nuel.

inner and outer pillars are articulated in such a way that the inner pillar forms a concave articular surface for the head of the outer pillar. In this way is formed a spiral tunnel filled with fluid, which is covered arch-like by the pillar heads. The nuclei of the pillar cells lie within a small amount of protoplasm in the side of the base of the pillar which is nearest to the tunnel. The number of the inner pillars is greater than that of the outer, as the outer pillars are the broader. The *hair-cells* are divided into inner and outer—that is, those that lie mesially and laterally to the pillar tunnel. There is always only *one* row of inner hair-cells and a somewhat varying number—generally three or four—of rows of outer hair-cells. They are short, columnar, nucleated cells, having a sharp process at the base, which does not reach the basilar membrane. On the surface they have fine stiff hairs. Between the outer hair-cells and nearly filling the space between their pointed basal processes are the *cells of Deiters*—long, narrow cells, which send a narrow process to the surface of the auditory cells. *Deiters' cells*, like the pillar cells, are supporting cells; the upper end lying between the auditory cells is slightly thickened into a head, known as the phalangeal process, so called because, when the organ of Corti is viewed from the surface, the heads of the cells appear


mv
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Kn
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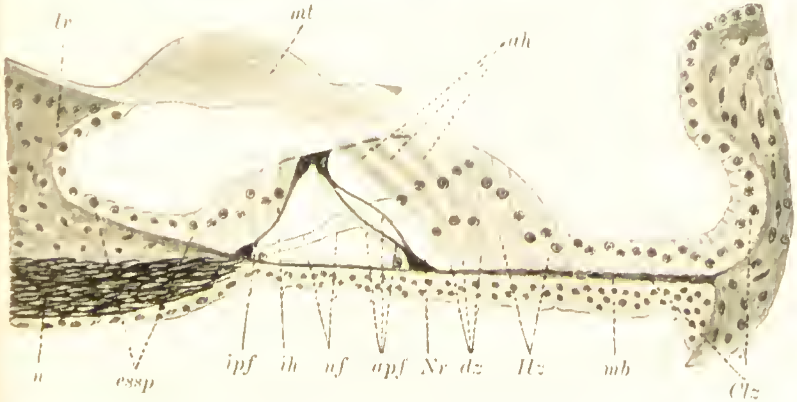
Fig. 64.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Nr
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Hz
mb
Clz

Fig. 65.

arranged in rows in the spaces between the auditory cells. Deiters' cells do not entirely fill the space between the pillars and the first row of hair-cells, and the space remaining is known as the space of Nuel, and is filled with fluid.

The cubic epithelium of the sulcus spiralis is attached to the inner hair-cells on the mesial side. The epithelium of the so-called zona pectinata, a name given to that portion of the membranous spiral lamina lying lateral to and not covered by the organ of Corti, is at first columnar and farther out cubic. Several rows of cells nearest to the organ of Corti are known as the cells of Hensen, while the remaining rows are the cells of Claudius.

The *cochlear branch* of the acoustic nerve runs in the *modiolus*, the osseous cochlear axis, from which it branches spirally in the base of the osseous spiral lamina and forms the *spiral ganglion*. The cells of the ganglion are bipolar. The neuraxes of the ganglion-cells form the acoustic fibers and the dendrites pass to the organ of Corti, the fibers running in the osseous spiral lamina to the labium tympanicum; they pass through small openings and at the same time become non-medullated. Part of these fibers run to the inner hair-cells, while part of them cross the tunnel to the outer hair-cells. They probably enter into union with the lower pointed ends of the cells, but only into contact, not into cellular connection.

The labyrinth, vestibule as well as cochlea, receives its blood-supply from a branch of the arteria auditiva interna (Art. labyrinthi), which forms capillary networks in the striæ vasculares, in the ganglion spirale, in the membrana spiralis, and the osseous walls of the scala tympani and vestibuli.

The labyrinth has no special lymph-vessels, but only the endolymphatic and perilymphatic lymph-spaces, which are connected with the lymph-spaces of the membranes of the brain.

Fig. 66.—Vertical section of the olfactory mucous membrane of a man who had been executed. × 250. Preparations made by Prof. K. W. Zimmermann, of Bern. The preparation was treated by the Golgi method. The upper portion of the epithelium was unrecognizable on account of the black precipitate. The connection of the olfactory fibers with the olfactory cells can be recognized. *E*, Epithelium; *O*, olfactory fibers; *R*, olfactory cells.

Fig. 67.—Vertical section of a taste-bud from the papilla foliata of the rabbit. × 500. The figure shows the typical picture of a taste-bud and its relation to the stratified pavement epithelium. *stg*, Gustatory rods; *dz*, tegmental cells.

Fig. 68.—View of the taste-bud from the taste-pore. × 500. From a section through the papilla foliata of the rabbit. The figure shows very distinctly the crown of the taste-rods. *ep*, Stratified pavement epithelium; *dz*, tegmental cells; *gz*, gustatory cells; *pg*, taste-pore; *stg*, gustatory rods.

THE ORGAN OF SMELL.

The *organ of smell* is in the olfactory region of the nasal cavity (see page 197). The *olfactory cells* are peripheral *ganglion-cells*, for their centripetal processes pass directly into a non-medullated olfactory fiber. They are long narrow cells, which include the entire thickness of the epithelium of the olfactory region and have in their center an enlargement containing a nucleus. The end of the cell which does not pass into a nerve-fiber extends to the surface of the epithelium, which here forms a fine cuticular formation, the membrana limitans olfactoria. The ends of the olfactory cells present fine hairs.

THE ORGAN OF TASTE.

The *organ of taste* is found in man principally in the form of taste-buds on the *circumvallate papillæ* of the tongue (see page 137), but also on other papillæ. The *papillæ foliatæ* of the *rabbit* contain numerous taste-buds.

The *taste-buds* are oval *epithelial structures*, pointed at the upper end; they lie in the stratified pavement epithelium in such a way that the broader base of the bud lies on the

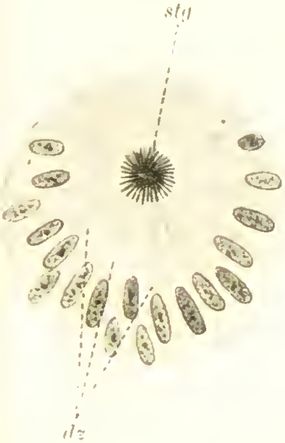

Fig. 67.

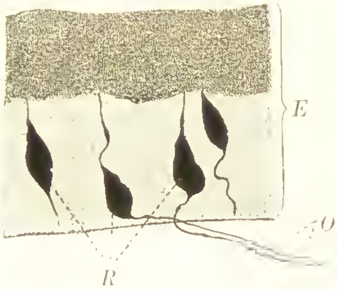

Fig. 66.

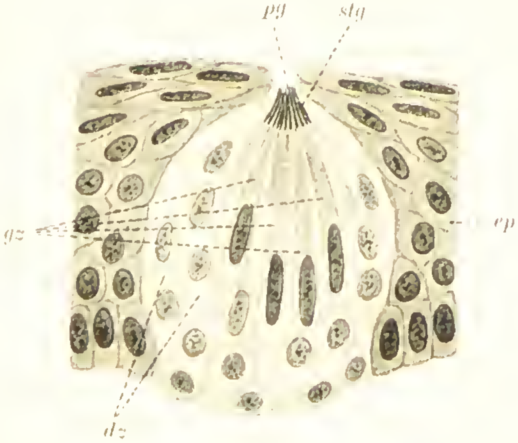

Fig. 68.

basal membrane, the point lying between the upper flattened layers of cells, but always at the level of the surface. At this point is found a funnel-shaped depression from the surface, the *taste-pore* or *canal*, into which the point of the taste-bud projects. The taste-buds themselves consist of two kinds of cells, gustatory cells and tegmental cells. The former are narrow, spindle-shaped cells, which occupy the center of the bud. Their points extend to the taste-pore and there bear a bright *rod-shaped process*, the *gustatory rod*. A group of rod-bearing cells is inclosed by tegmental cells. The latter are of different shapes, elongated, often crescent-shaped, nucleated cells, which surround in several layers the center of the bud which is formed by the gustatory cells. The gustatory cells are epithelial cells, like the auditory cells of the organ of Corti, and not ganglion-cells like the olfactory cells. In consequence of this the *nerve-fibers* of the N. glosso-pharyngeus, which have become non-medullated, enter into contact with the epithelial cells. We distinguish intergemmal fibers, which end between the taste-buds, and intragemmal fibers, which pass between the tegmental cells to the gustatory cells and end free between them.

INDEX.

Adenoid structures of tongue and pharynx, 138
  tissue, 53
Adipose tissue, 51
Adrenals, 193
Alveolar glands, 37
Amakrine cells, 223
Arrectores pilorum, 209
Arteries, 116
Astrocytes of neuroglia, 79
Auditory teeth, 235
Axis-cylinder of nerve-fibers, 75

Bile capillaries, 165
Bile-ducts, 165
Bladder, 173
Blood, 54
  and lymph vascular system, 114
  plasma, 55
  platelets, 61
Blood-corpuscles, 55
  red, 55
  white, 57
Blood-vessels, 115
  nerve-fibers of, 119
Bone, blood-vessels of, 82, 84
  canaliculi, 82
  development, 85
  endochondral, 85, 86
  intramembranous, 89
  nerves of, 85
  perichondral, 85, 87
  tissue, 81
Bone-cells, 81, 82
Bone-marrow, 84
  giant-cells of, 86, 91
  red, 61
Bowman's capsule, 167
  glands, 197
Bronchi, 198
Bronchial branches, 198
Bronchioles, 199
Bruch's membrane, 218

Canaliculi, bone, 82
Capillaries, 115
  bile, 165
  secretion, 36
Capsule of Glisson, 161
Cartilage, connective-tissue, 50
  elastic, 49
  hyaline, 49
  reticular, 49
  white fibro-, 50
Cartilaginous tissue, 48
Cell, 17
  amakrine, 223
  bone-, 81, 82
  centro-acinar, 160
  chief, of stomach, 143
  cone visual, 224
  corneal, 216
  Deiters', 236
  enamel, inner, 134
    outer, 134
  endothelial, 12
  ependyma, of neuroglia, 79
  epithelial, cornification of, 36
    relation of one to another 32
    special differentiation of, 33
  follicular, 187
  form of, 17
  ganglion-, 71. See also *Nerve-cells*
  giant-, 61

Cell, giant-, of bone-marrow, 86, 91
  goblet, 35
  Golgi's, 72
  hair-, 236
  lutein, 189
  mast-, of loose connecting tissue, 46
  membrane, 20
  nerve-, 71. See also *Nerve-cells*
  nucleus, 20
  of connecting tissue, 41
  of loose connecting tissue, 46
  olfactory, 238
  Paneth's, 146
  parareticular, 223
  parietal, 143
  pillar, 235
  plasma-, of loose connecting tissue, 46
  proliferation, 22
  protoplasm, 18
    foam theory of, 19
    structure of, 19
  Purkinje's, of cerebellar cortex, 101
  pyramidal, of cerebral cortex, 103
  rod visual, 223
  Sertoli's, 177
  size of, 18
  spider, of neuroglia, 79
  stellate, of liver, 165
  tendon, 93
Cementum, 131, 133
Central nervous system, 95. See also *Nervous system, central*
Centro-acinar cells, 160
Centrosome, 22
Cerebellar cortex, 98
    Purkinje's cells of, 101
Cerebral cortex, 103
    pyramidal cell of, 101
Ceruminous glands, 232
Chief cells of stomach, 143
Chlorid of hematin, crystals of, 57
Choroid, 217
  layers of, 217
Chromatin, 21
Chromosomes, 23
Cilia, 33
Ciliary body, 218
  glands, 230
  muscle, 218
  processes, 218
Club-hairs, 208
Cochlea, 234
  membranous, 234
Cochlear duct, 234
Colloid, 201
Concretions, prostatic, 183
Cone visual cells, 224
Conjunctiva bulbi, 231
  palpebrarum, 231
Connecting tissue, 40
    cartilage, 50
    cells of, 41
    elastic fibers of, 43
    fibrous elements of, 43
    formed, 45, 46
    gelatinous, 47
    ground substance of, 44
    loose, 45
      cells of, 46
      leukocytes of, 46
      plasma-cells of, 46
    lymph-vessels of, 53
    pigmented, 52
    reticular fibers of, 43
    simple fibrillar, 45
    white fibers of, 43
Corium, 203, 205
Cornea, 215
Corneal cells, 216
  endothelium, 216
Cornification of epithelial cells, 36
Corpus luteum, 189
Corpuscles, blood-, 55
    red, 55
    white, 57
  Grandry's, 112
  Hassal's, 127
  Herbst's, 113
  Malpighian, 167
  Vater-Pacinian, 112
Corti, organ of, 235
Cowper's gland, 183

Crusta, 20
Crystalloids, 20
Crystals, hematoidin, 57
  of chlorid of hematin, 57
Cuticula dentis, 133
  of hair, 206
Cutis, 203
  layers of, 203

DEITERS' cells, 236
Dendrites, 72
Dentinal fibers, 131
  papilla, 134
  sac, 135
Dentine, 131
Deutoplasm, 189
Digestive organs, 128
Dilatator muscle of pupil, 219
Droplets, fat, 20
Ducts, system of, 38
Ductus cochlearis, 234
Duodenal glands, 148
Duodenum, 147

EAR, 232
Efferent seminal passages, 180
  urinary passages, 173
Egg tubes of Pflüger, 187
Ejaculatory duct, 182
Elastic cartilage, 49
  fibers of connecting tissue, 43
  tissue, 17
Eleidin granules, 36
Enamel, 131, 132
  cells, inner, 134
    outer, 134
  ledge, 133
  organs, 133
  pulp, 134
Endocardium, 114
Endochondral bone, 85, 86
Endomysium, 91
Endoneurium, 107
Endothelial cells, 12
Endothelium, corneal, 216
  of iris, 219
Ependyma cells of neuroglia, 79
Epicardium, 115
Epidermal structures of skin, 205
Epidermis, 202
  layers of, 202
Epineurium, 10
Epiphysis, 107
Epithelial cells, cornification of, 36
    relation of, to each other, 32
    special differentiation of, 33
  tissue, 29
Epithelium, simple ciliated, 31
    columnar, 30
    cubic, 30
    flattened, 30
  squamous, 30, 31
  stratified ciliated, 31
    columnar, 31
    pavement, 31
  transitional, 32
Erythrocytes, 55
Esophagus, 141
Eye, 214
  tunica externa of, 215
    interna of, 221
    media bulbi of, 217
Eyeball, auxiliary apparatus of, 229
Eyelids, 229

FAT droplets, 20
Female reproductive organs, 185
  urethra, 174
Fiber, dentinal, 131
  elastic, of connecting tissue, 43
  Müller's, of retina, 222
  nerve-, 75. See also *Nerve-fibers*
  reticular, of connecting tissue, 13
  Sharpey's, 84
  white, of connecting tissue, 43
Fibrillar connecting tissue, simple, 15
Fibro-cartilage, white, 50

Fibrous elements of connecting tissue, 43
Flagella, 33
Foam theory of cell protoplasm, 19
Follicles, lymph, 121, 122
    agminated, 122
    solitary, 122
Follicular cells, 187
Formed connecting tissue, 45, 46
Fovea centralis of retina, 226

Ganglia, peripheral, 108
  spinal, 108
  sympathetic, 109
Ganglion-cells, 71. See also *Nerve-cells*
Gelatinous connecting tissue, 47
Germinal epithelium of ovary, 186
Giant-cells, 61
  of bone-marrow, 86, 91
Glands, alveolar, 37
  Bowman's, 197
  ceruminous, 232
  ciliary, 230
  Cowper's, 183
  duodenal, 148
  forms of, 37
  hemolymph, 123
  lachrymal, 231
  lymph-, 121
  mammary, 213
  of Moll, 230
  olfactory, 197
  parotid, 155
  pyloric, 141
  salivary, 153
  sebaceous, 210
  sublingual, 158
  submaxillary, 155
  sweat-, 211
  thyroid, 201
  tubular, 37
  unicellular, 35
Glandula bulbourethralis, 183
Glisson, capsule of, 161
Glomerulus, 167
Goblet-cells, 35
Golgi's cells, 72
Grandry's corpuscles, 112
Granules, eleidin, 36
  keratohyalin, 36
  pigment, 20
  tigroid, 20
  zymogen, 20, 35
Ground lamellæ, 82
  substance of connecting tissue, 44

Hair, 205
Hair-cells, 236
Hair-shaft, 206
Hair-sheath, 207
Hassal's corpuscles, 127
Haversian canals, 82
  lamellæ, 82
Hearing, organ of, 232
Heart, 114
  muscle, 68
Hematin, chlorid of, crystals of, 57
Hematoidin crystals, 57
Hemin, 57
Hemoglobin, 57
Hemolymph glands, 123
Henle's fibrillar sheath, 108
  layer, 207
  loop, 168
Hepatic vein, 164
Herbst's corpuscles, 113
Howship's lacunæ, 91
Huxley's layer, 207
Hyaline cartilage, 49
Hyaloplasm, 19
Hypophysis, 106

Interstitial lamellæ, 83
Intestine, large, 149
  small, 145
Intestines, blood-vessels of, 151
  lymphatic structures of, 149
  lymph-vessels of, 151
  nerves of, 151
Intralobular vein, 164
Intramembranous bone, 89

Involuntary muscle, 62
  musculature, 63
Iris, 219
  blood-vessels of, 219
  endothelium of, 219
  layers of, 219
  muscle of, 219
  stratum proprium of, 219
Islands of Langerhans, 160

KERATOHYALIN granules, 36
Kidney, 166
  blood-vessels of, 170

LABYRINTH, 233
Lachrymal glands, 231
Lacunæ, bone, 82
  Howship's, 91
Lamellæ, bone, 82
  ground, 82
  Haversian, 82
  interstitial, 83
Lamina choriocapillaris, 218
  propria of choroid, 217
  spiralis membranacea, 234, 235
    ossea, 234
Langerhans, islands of, 160
Large intestine, 149
Larynx, 197
Lens, 229
Leukocytes, 57
  of loose connecting tissue, 46
Ligaments, 84
Lingual tonsils, 138
Linin, 21
Liver, 161
  lobules, 161
  stellate cells of, 165
Loose connecting tissue, 45
    cells of, 46
    leukocytes of, 46
    plasma-cells of, 46
Lungs and bronchial branches, 198
  blood-vessels of, 200
  lymph-vessels of, 200
  nerves of, 201
Lutein cells, 189
Lymph follicles, 121, 122
    agminated, 122
    solitary, 122
  vascular system, 114
Lymphatic structures of intestines, 149
Lymph-glands, 121
Lymphocytes, 57, 58
Lymphoid tissue, 53, 120
Lymph-vessels, 120

MALE reproductive organs, 175
  urethra, 183
Malpighian corpuscle, 167
Mammary glands, 213
Marrow, bone-, 84
    red, 61
Medulla of hair, 206
Medullated nerve-fibers, 75
    myelin of, 77
Meissner's plexus, 153
Membrana propria, 40
  vestibularis, 234
Membrane, cell, 20
  nuclear, 21
Microscopic anatomy of the organs of the body, 81
Microsomes, 19
Mitosis, 22
Moll, glands of, 230
Motor nerve-endings, 109
Müller's fibers of retina, 222
Muscle, 91
  ciliary, 218
  heart, 68
  involuntary, 62
  transversely striated, 64
  voluntary, 64
Muscular system, organs of, 91
  tissue, 62
Musculature, involuntary, 63
Myelin of medullated nerve-fibers, 77
Myelocytes, 61
Myocardium, 114

NAIL-BED, 209
Nails, 209

- Nasal cavity, 196
- Nerve, optic, 227
- Nerve-cells, 71
  - form of, 71
  - neurofibrils of, 73
  - nucleus of, 72
  - protoplasm of, 72
  - tigroid substance of, 73
- Nerve-endings, 109
  - motor, 109
  - sensory, 109, 110
    - encapsulated, 110, 111
    - free, 110, 111
- Nerve-fibers, 75
  - axis-cylinder of, 75
  - medullated, 75
    - myelin of, 77
  - non-medullated, 75
- Nervous system, central, 95
      - blood-vessels of, 105
      - lymph-vessels of, 106
      - membranes of, 106
    - organs of, 95
    - peripheral, 107
  - tissue, 70
- Neuraxis, 72
- Neurilemma, 77
- Neurofibrils of nerve-cells, 73
- Neuroglia, 78
  - ependyma cells of, 79
  - spider cells of, 79
- Neuromuscular spindles, 92
- Neurones, 71
- Neuroplasm, 75
- Neurotendinous spindles, 95
- Nissl's bodies, 73
- Nodes of Ranvier, 76
- Non-medullated nerve-fibers, 75
- Nuclear membrane, 21
  - sap, 22
- Nucleoli, 21
- Nucleus of nerve-cells, 72

- ODONTOBLASTS, 131, 135
- Olfactory cells, 238
  - glands, 197
- Optic nerve, 227
- Ora serrata, 221, 225
- Oral cavity, 129
- Organ of Corti, 235
- Osseous tissue, 81
- Osteoblasts, 87
- Osteoclasts, 86, 91
- Otoliths, 233
- Ovary, 185
- Oviduct, 191

- PANCREAS, 158
- Paneth's cells, 146
- Parareticular cells, 223
- Parietal cells, 143
- Parotid gland, 155
- Penis, 185
- Perichondral bone, 85, 87
- Perimysium, 91
- Perineurium, 107
- Periosteum, 84
- Peripheral ganglia, 108
  - nerves, 107
  - nervous system, 107
- Peyer's patches, 149
- Pflüger, egg tubes of, 187
- Pharyngeal tonsils, 139
- Pharynx and tongue, adenoid structures of, 138
- Pigment granules, 20
- Pigmented connective tissue, 52
- Pillar cells, 235
- Pineal gland, 107
- Plasma, blood, 55
- Plasma-cells of loose connecting tissue, 46
- Plasmodia, 22
- Platelets, blood, 61
- Portal vein, 162
- Proliferation of cells, 22
- Prostate, 183
- Prostatic concretions, 183
- Protoplasm, 18
  - cell theory of, 19
  - of nerve-cells, 72
  - structure of, 19
- Purkinje's cells of cerebellar cortex, 101
- Pyloric glands, 144
- Pyramidal cell of cerebral cortex, 103

- Ranvier, nodes of, 76
- Red blood-corpuscles, 55
  - bone-marrow, 61
- Reissner's membrane, 234
- Reproductive organs, female, 185
  - male, 175
- Respiratory organs, 196
- Reticular cartilage, 49
  - fibers of connecting tissue, 43
- Retina, 221
  - fovea centralis of, 226
  - layers of, 221
  - Müller's fibers of, 222
  - optic papilla of, 227
  - ora serrata of, 221, 225
- Riolani, ciliary muscle of, 231
- Rod visual cells, 223
- Root-sheath of hair, 207
- Rouleaux, 55

- Sacculus, 233
- Salivary ducts, 155
  - glands, 153
- Sarcoplasm, 66
- Schwann, sheath of, 77
- Sclera, 215, 216
  - blood-vessels of, 216
  - nerves of, 217
- Sebaceous glands, 210
- Secretion capillaries, 36
- Semicircular canals, 233
- Seminal passages, efferent, 180
  - vesicle, 182
- Sense organs, special, 214
- Sensory nerve-endings, 109, 110
  - encapsulated, 110, 111
  - free, 110, 111
- Sertoli's cells, 177
- Sharpey's fibers, 81
- Sheath of Schwann, 77
- Simple epithelium, 30. See also *Epithelium*
  - fibrillar connecting tissue, 45
- Skeletal system, 81
- Skin, 201
  - epidermal structures of, 205
  - glands of, 210
  - nerves of, 212
- Small intestine, 145
- Smell, organ of, 238
- Special sense organs, 214
- Spermatids, 177, 179
  - development of, into spermatosomes, 177
- Spermatoblast, 177
- Spermatocytes, 177, 179
- Spermatogones, 179
- Spermatosomes, 176
  - development of, from spermatids, 177
- Sphincter muscle of pupil, 219
- Spider cells of neuroglia, 79
- Spinal cord, 95
  - ganglia, 108
- Spleen, 124
- Spongioblasts, 223
- Squamous epithelium, 20, 31
- Stellate cells of liver, 165
- Stomach, 143
  - blood-vessels of, 151
  - lymph-vessels of, 151
  - nerves of, 151
- Stratified ciliated epithelium, 31
  - columnar epithelium, 31
  - pavement epithelium, 31
- Stratum corneum, 202
  - germinativum, 203
  - granulosum, 203
  - lucidum, 203
  - spinosum, 203
- Sublingual gland, 158
- Submaxillary gland, 155
- Suprarenals, 193
- Sweat-glands, 211
- Sympathetic ganglia, 109
- Syncitia, 22
- System of ducts, 38

- Tactile meniscus, 111
- Taste, organ of, 238
- Taste-buds, 238
- Teeth, 130
  - auditory, 235
- Tela subcutanea, 203
- Tendon cells, 93
- Tendons, 93
- Testis, 175

Testis, blood-vessels of, 180
  nerves of, 180
Thymus, 126
Thyroid gland, 201
Tigroid granules, 20
  substance, 73
Tissue, 28
  adenoid, 53
  adipose, 51
  bone, 81
  cartilaginous, 48
  connective, 40
    cells of, 41
    elastic fibers of, 43
    fibrous elements of, 43
    ground substance of, 44
    lymph-vessels of, 53
    reticular fibers of, 43
    simple fibrillar, 45
    white fibers of, 43
  elastic, 47
  epithelial, 29
  formed connecting, 45, 46
  gelatinous connecting, 47
  loose connecting, 45
      cells of, 46
      leukocytes of, 46
      plasma-cells of, 46
  lymphoid, 53
  muscle, 62
  nervous, 70
  osseous, 81
  pigmented connective, 52
Tomes' granular layer, 132
Tongue, 136
  and pharynx, adenoid structures of, 138
  blood-vessels of, 140
  lymph-vessels of, 140
  nerves of, 141
Tonsillar crypt, 138
Tonsils, lingual, 138
  pharyngeal, 139
Tooth pulp, 130
Trabeculæ of lymph-glands, 121
Trachea, 198
Transitional epithelium, 32
Tubular glands, 37
Tunica externa of eye, 215
  interna of eye, 221
  media bulbi of eye, 217
Tympanic membrane, 233

UNICELLULAR glands, 35
Ureter, 173
Urethra, female, 174
  male, 183
Urinary organs, 166
  passages, efferent, 173
Uriniferous tubules, 167
Uterus, 191
Utriculus, 233

VAGINA, 193
Vas deferens, 181
Vascular system, lymph, 114
Vater-Pacinian corpuscles, 112
Veins, 118
  hepatic, 164
  intralobular, 164
  portal, 162
Vision, organ of, 214
Visual cells, cone, 224
    rod, 223
Vitreous body, 228
Volkmann's canals, 83
Voluntary muscle, 64

WHITE blood-corpuscles, 57
  fibers of connecting tissue, 43
  fibro-cartilage, 50

YOLK-NUCLEUS, 189

ZONULA ciliaris, 228
Zymogen granules, 20, 35

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See page 22 for a List of Contents classified according to subjects

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